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Contents

Prologue

To address the complex social and environmental issues of this century, various models of knowledge production have been proposed that transcend disciplinary, institutional, and cultural boundaries. Among them, Transdisciplinary Science stands out, representing an idealization of how scientists, researchers, and academics should work while integrating the wide diversity of social actors affected by these problems.

Transdisciplinary Science is understood as a reflective and integrative method-driven approach, which aims to produce knowledge and design relevant solutions to address the problems facing humanity. At the core of this approach, integration stands out as a desire to discover, assimilate, analyze, and utilize heterogeneous knowledge through teamwork processes. Ideally, this integration is achieved in levels: framing the problem, managing the project, including team members and stakeholders, managing data, synthesizing results, and applying knowledge.

Because scientific research is often situated at the confluence of science, policy, and practice, it is understood that the inclusion of different stakeholders and disciplines interested in knowledge production must be a priority. As evidenced in this book, effective adaptation and harnessing of science requires informed policy-making, which in turn demands that research paradigms evolve toward the integration of natural, human, and social science approaches with knowledge in each discipline.

In the same vein, with the blurring of disciplinary boundaries and the involvement of society in problem-solving, important questions arise regarding the production of knowledge, which may limit the degree to which society is effectively empowered to deal with them. If science is a work of composition, involving the mobilization and translation of different knowledge systems, which do not necessarily share the same ontology, then what does it mean to integrate different knowledge in transdisciplinary settings?

The authors' work in this book seems to answer this question because, in the realization of their projects, they apply specific related theories to effectively realize the imperative of transdisciplinary integration of science. This is evident in each chapter, where they express ideas about the co-production of knowledge, social learning, and team science ecology for the New Era. In this text, Transdisciplinary Science starts from the premise that integration can and should be the regulatory ideal. The results presented support the imperative that integration masks the friction, antagonism, and power inherent in the co-production of knowledge that can preclude innovative and experimental ways of understanding science and adapting it to find solutions to humanity's pressing problems.

The book is set in the context of adaptation to major changes in the New World Order, a field increasingly characterized by transdisciplinary discourse and methodological experimentation. An adaptation that takes place locally as well as globally, so that the integration of knowledge and the production of relevant solutions to the challenges must be considered especially urgent. That is the complexities of adapting to the New Era demand relevant knowledge, coming from diverse disciplines and perspectives, and application that bridges the gap in disciplinary science. As evidenced in this book, Transdisciplinary Science is possible, and the reader will find common factors and patterns that make it an attractive model for scientists, researchers, and scholars to pursue social adaptation, despite the practical and epistemological challenges facing humanity in this century.

On the other hand, scientific work is heterogeneous and requires diverse actors and different points of view, however, it also requires convergence and cooperation to generate adequate results and a product of general utility. As a research paradigm, Transdisciplinary Science is a bottom-up approach that allows directing science and its results toward broad conglomerates of scientists and society, working together to address the complex problems of the New World Order. This collaborative work is characterized by a knowledge co-production approach because research is conducted with the *users of knowledge through* projects aimed at informing and stimulating socio-economic-human development.

The research results presented in this book are a disinterested endorsement of Transdisciplinary Science, in part motivated by its promise to balance epistemological heterogeneity and the broader demands of knowledge convergence around the survival of humanity. In this sense, the reader may realize that the results are *credible* because they fit the evidence and arguments; *salient*, because they are relevant to the needs of decision-makers; and *legitimate*, because they generate respectful, unbiased, and fair knowledge.

The content of the chapters of this text reveals critical procedural and epistemological factors that reflect the co-production of knowledge in a methodologically sound manner. The areas in which the authors work focus on structural, institutional, behavioral, and relational factors that influence the effective creation of transdisciplinary teams and the co-production of rigorous scientific knowledge. Factors such as project structuring, team composition, mechanisms to foster knowledge integration, and trust and communication to meaningfully co-produce data, claims, and results are highlighted. In addition, social learning from content and integration of different stakeholders and reflective and iterative research practice is a hallmark of the transdisciplinary efforts in this book.

In this fundamental alchemy of Transdisciplinary Science, a shared conceptual framework on the issues and on how to bridge methodological, epistemological, organizational, and personal boundaries is achieved. In these studies, it is considered that integration may be an epistemological barrier, but given the effective integration of adaptation and comprehensive knowledge sharing among multiple stakeholders, the identification of the appropriate object of study is noted in the content as necessary to bridge the various knowledge systems and society.

Although the research results presented in this book are a reflection of the integrative action of knowledge, they cannot be interpreted as a simple organizational, epistemic, or passing matter, because Transdisciplinary Science is not achieved simply by assembling the right object, method or equipment. As the reader may notice, the studies and results, practical and theoretical, contained in the text are the reflection of integration as an ontological issue, something that manifests itself in the research practices contained and oriented to the generation of hybrid or relational objects while solving problems that resist the efforts of the disciplinary partition of science into natural and social fractions. This is a way of blurring the difference between conflicting forms of knowledge within science and as a means of depoliticizing science and excluding it from adequate possibilities for the development, survival, and sustainability of humanity.

The purpose of the Sustainable Development Goals SDG is to promote an integrated solution to the challenges facing humanity in the New World Order. The United Nations recognizes the need to further mainstream sustainable development at all levels, integrating economic, social, and environmental aspects, and recognizing their interrelationships, to achieve sustainable human development in all its dimensions. Similarly, evaluations of research programs and policies in the New Era, while recognizing the scientific achievements to date, conclude that the challenges ahead require new and more integrative initiatives on a larger scale based on transdisciplinary science.

Increasing evidence supports the conclusion that the Planet has entered a New Era in which humans dominate and control global processes. Data show an increased frequency of extreme weather events and multiple natural systems operating beyond planetary boundaries, and trajectory models indicate that they are likely to increase at a faster rate in the coming decades. With the world's human population expected to soon reach 9 billion, mostly living in urban and industrialized centers, the human impact on the planet looks set to increase. Awareness of these trends is sufficiently widespread to recognize that human activities are indeed affecting the structure and functioning of the *Earth system* as a whole.

Knowledge best suited to the New Era cuts across standard scientific disciplines and the divide between science and other forms of systemic knowledge; even the image of the last century, in which humanity's development, survival, and sustainability were underpinned by the economic, social and environmental, does not fit the integrated challenges of the New Era. Both the natural and the social and human sciences are key pieces of the puzzle in this century because as social systems increasingly interact with the global environment, ideas drawn solely from one science or the other are more likely to remain impractical. In this scenario, Transdisciplinary Science is crucial to obtain adequate knowledge, because models of integration of social and environmental systems are increasingly necessary to have a more complete view of the challenges of the New World Order. Therefore, the integration of scientific and social knowledge, especially relevant in the chapters of this book, becomes a support for the challenges of the New Era.

A global Transdisciplinary Science, such as the one presented in the chapters of this book, implies forms of engagement different from those of scientific bodies focused on global governance because it requires developing trust in relationships and a deep reflective dimension that includes a continuous normative and deliberative debate. Analytically the content of this book assumes that the main impact of global Transdisciplinary Science will be on global research and governance, i.e., on sources of global authority that exercise power across borders to impact life in every sense. Therefore, the focus of this text is not on the construction of Transdisciplinary Science, but on its application for the benefit of humanity.

The authors and the publisher assert that the political response may be a key factor limiting the impact of global Transdisciplinary Science, so it is necessary to distinguish between responses by excision, discursive, and transformative. The first occurs when debate and disputes are organized around stable blocks of actors, in which context the integration of science occurs through negotiation and punctual patterns because the members form blocks in which they largely retain persistent personal and disciplinary interests and identities. The discursive response involves the discussion of ideas, regulations, and cause-effect relationships, through processes of deliberation and justification in an environment in which the actors have defined interests, but through these processes, they learn about their interests creating opportunities for shared ones. For its part, the transformative response occurs in an ambiguous process in which the actors develop shared knowledge about their interests, although the response and debate are active, the actors change their positions, modify their ideas, and develop collective knowledge throughout the process.

The balance between these different forms of response determines how the global Transdisciplinary Science is developed. In any case, this book is a contribution to its development and use, because the authors are aware of the need for science to work in an integrative way and oriented to the efficient and effective resolution of global problems. Each of the chapters reflects the intention to help the Planet, both from a practical and theoretical point of view, but with replicable results, because they have been achieved through joint work with all the actors involved in each problem analyzed. We hope that the reader will find what is necessary to understand and continue the idea of Transdisciplinary Science because this is the basis for the development and survival of humanity.

I

Analysis of the need for digital business transformation amid economic recovery[1]

The impacts of the digital revolution on businesses became more visible and intensified in the wake of the Covid-19 pandemic, revealing their shortcomings in the face of the reality of the New World Order. As evidenced in many countries, the remote provision of services in education, health, and commerce, as well as telework and social relations, increased and permeated most activities, although to varying degrees and levels in countries where new technologies have not yet entered or are just beginning to be recognized. This chapter presents a description of the digital transformation scenario, including its influence on institutional development, and analyzes aspects of the new technologies related to economic reactivation after the Covid-19 pandemic.

[1] This chapter is a product of the research project *Framework for the integration of new technologies to the productive sector, oriented to economic reactivation in the post-pandemic framework*, financed by the Francisco José de Caldas National Fund for Science, Technology, and Innovation, through the Ministry of Science, Technology, and Innovation (Minciencias).

1. INTRODUCTION

Digital transformation is imperative for all businesses, from the smallest to the largest, and the message is heard from speeches, panel discussions, articles, or studies discussing how companies can be competitive and stay relevant as the New World Order drives humanity towards digital. But what is still unclear for many of these businesses is what does digital transformation mean? What are the steps that need to be taken to achieve it? Does it require more people to do it? What components of the business infrastructure need to change? Or is it worth a try?

Some even consider that the term is so widely used that it seems to have become obsolete. The point is that, regardless of whether the term is accepted or not, everything it involves in itself: rethinking operating and business models, experimenting with commercial alternatives, improving the quality and agility of production, and responding to customer demands, among many others, have to be addressed within the framework of globalization. In any case, it should be noted that companies, often without realizing it, are already going through different stages in the process of digital transformation.

The reason is that digital technologies are growing exponentially and their use is becoming more widespread across the planet: connectivity reaches a large part of society and smartphones offer access to information, social networks, commerce, and entertainment like never before. These innovations are accelerating technological development and devices are being used for cloud computing, big data capture and analysis, and supply chains, all of which are considered important aspects for companies in this century. This revolution has brought major changes in production and business strategies, although not all companies have seen the advantages of participating in it.

Many support their decision not to join this trend because technological progress is exclusionary since a large part of society does not have access to the benefits it offers, especially because incomes are not equitable for all people. This has opened a gap between supply and demand for digital, because, although the coverage is wide, commercially in many countries it is not yet reflected in the use. This is why it cannot be hidden that the balance between the benefits and costs of digital transformation is still unbalanced; in addition, geopolitical struggles related to patents, standards, and digital production, in addition to digital insecurity, weaken the decision-making of companies. On the other hand, social and economic inequality in many countries and the progressive exclusion of vulnerable populations make it difficult to achieve the equitable construction of social and political systems that help companies adequately manage their digital transformation.

On the other hand, many companies had begun this decade structuring development plans to remain relevant in globalization and participate in the markets that open up every year, but they did not expect events such as the Covid-19 pandemic, which led them to backtrack in their attempts. In any case, one issue they did not consider at the time was the new opportunities and challenges that opened up in that contingency.

While companies around the world were affected by the crisis and faced difficulties in maintaining a position of structural credibility, it seems that the economic recovery has accelerated and many of them, once again, we're not prepared to make the best of it. Today they are forced to remedy the fall in investment and the stagnation of productivity, and for this, they will have to renew their business model, overcome the problems, and undertake a new drive to contribute to economic, social, and environmental sustainability, while achieving structural change by incorporating the necessary technology to diversify their production system in the post-pandemic economic reactivation [1].

In this context, the key is not to jump into change without a structured plan for the integration of new technologies, because companies need to analyze and discuss their specific needs before deciding on one technology or another. After all, the most important thing is to pave the way for inclusive and sustainable digitization, i.e., in addition to creating the conditions for economic recovery, they must also improve quality and productivity. In this way, they will make better use of new technologies, increase productivity, and offer better jobs and wages. At the same time, these changes encourage the emergence and diffusion of new ideas, products, and production techniques, while helping to generate new jobs and forcing employees to redefine their qualifications and skills.

The reason for all this is that, while it is true that technological change drives economic growth in the medium and long term, as well as productivity and living standards, it is also true that the emergence and dissemination of new knowledge, ideas, products, and production techniques generates a process of *creative destruction*. That is why we must be prepared, because, in many industries, digital transformation redefines jobs, which forces workers to become qualified, but also generates new jobs, which require skills, abilities, and capabilities different from the traditional ones [2].

This reality has been experienced before in human history, with new industries replacing old ones and workers having to adapt their skills to the New World Order. But let's be clear, technology cannot be blamed for all this, because, although its most predominant impact is on employment, real mechanisms are needed to integrate new technologies into the productive sector with a focus on economic reactivation. Moreover, if jobs are not to be affected, the deficiencies in the education system must also be corrected promptly.

In this sense, to achieve a consistent and credible integration of new technologies, reforms in policy practices are needed while overcoming institutional inertia. To achieve success, the State must achieve coordination between related ministries and the participation of all stakeholders; establish controls against internal failures, and put the social good before particular interests, while adopting a global perspective that allows a real understanding of the impacts of digital transformation. In addition, measures must be established to improve the qualification of workers, thinking about it from the very moment of their entry into the education system.

Intended as a contribution to the clarification of the term digital transformation and its impacts on economic development and recovery, this chapter describes the context related to such transformation while presenting the personal, social, business, and government needs to achieve it successfully in the industry.

2. DIGITAL TRANSFORMATION

So far in the 21st century, human and social development has gone hand in hand with rapid changes in technology and increasing production and distribution of digitized devices and services, both at a personal and business level. And, as the century progresses, it seems that these changes will accelerate as the development of artificial intelligence, robotics, biotechnology, and nanotechnology, among others, is perfected. These technologies were, and are currently, of broad benefit in addressing the 2020 pandemic through the accelerated development of vaccines and subsequent studies to address variants. But while this reality cannot be hidden, when advances emerge so rapidly they may outpace societies' ability to adapt to them, leading to serious drawbacks in terms of acceptance and support. For example, in the last decade, jobs that until recently were taken for granted in the industry have disappeared; on the other hand, social networks promote social divisions, generate anxiety, and many doubts about ethics and privacy protection [3].

Because of all this, there is still a concern in society that the new technologies will widen these inequalities or, in general, create new ones. While many of these problems are manifested in developed countries, the implications are more serious for developing countries, since societies, in their eagerness to stay at the forefront of what is happening in the world, suffer from anxiety and are overwhelmed by the feeling that they are lagging. But this is not exclusive to individuals, because companies and industries are also affected, which leads them to make hasty decisions, either to achieve a favorable economic revival, enter the New World Order, or simply to keep up with globalization. That is why they rush into acquiring technologies without structural studies and fail because digital transformation is not a gut decision, but a formal project of needs versus opportunities for improvement.

To understand the term digital transformation, we must first understand that this century is a time of dramatic technological advances and, although they are most noticeable in developed countries, social inequalities in this regard have been present since the First Industrial Revolution. By then, the majority of people in all countries were equally poor and the differences between countries were much smaller (Figure 1). But with the advent of technological change, the gap became noticeable and those who were able to take advantage of it advanced faster than the others, who lagged and remained on the periphery.

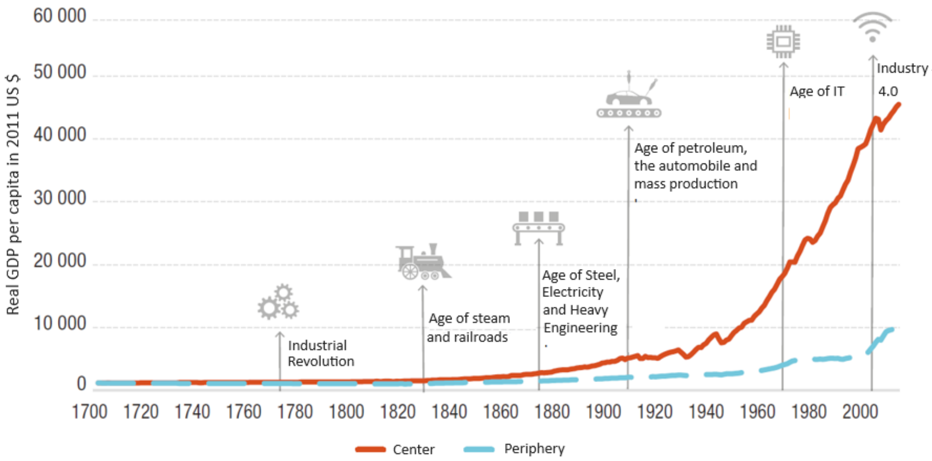

Figure 1. Technological change and inequality across ages [4]

From then on, and with each wave of development, this inequality became more noticeable, and access to social products and services became more difficult, not to mention public goods, since, in health, education, IT infrastructure, and coverage, pressing unmet needs were consolidated. But this cannot be a barrier to falling behind, because, as some East Asian countries have shown, through an educational revolution, technological learning, ingenuity, and innovation, it is possible to catch up and keep up with developed countries.

Because of all this and because digital transformation is seen differently in each society, country, or company, it is difficult to find a generalized definition. However, it can be defined as *the integration of new technologies in all areas of the company or industry*, which generates fundamental changes in the way they work, innovate, and generate quality. But, beyond the technical issue, a *cultural change is needed that challenges the business model, the traditionality of workplaces, and the capabilities of employees*. This means that companies must abandon the processes on which they were built, and favor revolutionary new practices that are still under development. The point is that one cannot overthink because the development of new technologies is permanent, but neither should change be initiated without a needs assessment tailored and structured to each company.

For many entrepreneurs, the question then arises: why is digital transformation important in this day and age? The point is that there are many and varied reasons for doing so, but the main one is that staying relevant in the New World Order is a matter of survival. In addition, and because of the pandemic, it is critical to recover, restructure, or develop the ability to quickly adapt to supply chain disruptions, time-to-market pressures, and rapidly changing customer expectations in pace with new technologies [5]. This is why digital transformation is seen as a must-have option for economic recovery.

Likewise, due to the crisis generated by Covid-19 in the productive sector, the what, why, and how of digital transformation have been reconfigured [6]. This reality is experienced more strongly in the employee experience which, although it has been a key issue in organizations, today has a mixed reception, sometimes stereotyped, in which it is made to think that only operators are needed waiting for the best technology with reduced budgets. On the other hand, much of the workforce performs its functions remotely, making the experience come down to digital technology as the only way work can get done. In addition, in response to the pandemic, companies seek to adopt the notion that *the perfect is the enemy of the good*. As a result, it is worth noting that, as a result of the dramatic disruption, many organizations have had to *renegotiate* their relationship with new technologies, prioritizing the retraining of employees to develop the skills required in the new context.

But the question is not so simple, because it is necessary to take into account a series of social and cultural aspects that are involved in achieving success in the digital transformation [6]. Starting because in this century companies have changed their perception of IT departments, observing them as one more that must generate revenue. The integration of new technologies has made managers shift their operational priority from *improving business processes* to *developing new innovative products* to turning IT, managers, into digital leaders. So instead of focusing on cost savings for these departments, they are now looking to make them the main driver of business innovation. However, adopting this operational thinking requires all players to reconsider the role and impact of new technologies on their business model.

This is because, while new technologies play an important role in the digital transformation strategy, the process of implementing them and adapting to the accompanying changes is everyone's responsibility. This is why digital transformation is a people problem, in part because today, more than ever, employees work in cross-functional teams, and, at some point, the transformation initiative will reshape them, including entrenched roles and business processes. That socio-cultural aspect makes people fear the loss of their jobs, which directly impacts the transformation backlash. What this has done is make young professionals accept that they need to develop so-called soft skills, demanding from the education system a revolution in its rusty foundations.

This situation has made the lack of educational innovation in universities more evident since businessmen want to hire professionals with skills, capabilities, and abilities oriented to the use and potentization of new technologies in the business model. But this is not always easy to achieve, because most of these professionals are simple operators of a tool, without sufficient capacity to innovate its use or to adapt it to functions that had not been budgeted for before. In addition to this situation, another aspect that hinders to some extent a proper digital transformation is veteran employees, those who follow the book to the letter, and lone wolves. This forces companies to think about employees in a segmented way and must structure retraining plans for each particular segment. The reason is that, from the perspective of digital transformation, it is folly to structure personal adaptation processes for all employees in the same way. Their experiences, preferences, behavior, and acceptance of new technologies must be taken into account.

3. DIGITAL TRANSFORMATION AND QUALITY

Although the impact of new technologies on the productive sector has been studied mainly from a technological point of view [7], partly because advances are manifested at this level [8], it turns out that technology is not the most important promoter of digital transformation [9], as it is just one more component of the process that organizations must develop to remain competitive in the New World Order [7].

From this perspective, it is important to analyze the implications of digital transformation regarding quality, and, while some claim that in this context innovation has been made about quality [10], the reality is that this discussion remains active from the scientific and professional [11, 12]. This has led to the emergence of two camps in the discussion, on the one hand, those who focus on how to achieve progress and make the most of the opportunities of digital transformation and, on the other hand, those who strive to ensure the best performance of new technologies.

The first approach focuses on quality concepts, strategies, methods, and tools in the integration process, such as quality assurance or performance improvement. Others analyze the opportunities and challenges for quality depending on the type of organization, concentrating on issues such as strategic alignment, supply chain integration, or process and product information monitoring. On the other hand, those analyzing technological performances highlight the potential of using new technologies to improve quality and business performance.

Both perspectives are fine, what happens is that they are not properly integrated, impairing the process and the understanding of the impact of new technologies on quality management in the process of digital transformation. Generating a situation that makes it difficult to properly understand the relationship and most companies still do not have structure-specific strategies or models for the integration of new technologies, in which quality is adequately addressed [13]. Therefore, finding a generalist approach to quality in digital transformation is a question that, so far, seems to be relegated to the theoretical, leaving practical implementation undeveloped. This may be a consequence of the fact that efforts and budgets in quality management are almost exclusively allocated to new production technologies [14]. What this increased emphasis on technology demonstrates is that it is technologists, not quality specialists, who make the decisions about quality management in the digital transformation.

This technology-driven approach to quality has benefits and raises expectations, and many industries may find it suitable for their production model and for improving quality control and management. However, in most companies, it is necessary that this integration also involves a perspective driven by quality itself, because doing it only from the technological limits creativity in terms of quality [10]. Moreover, it becomes critical when analyzing the products of this century, which are increasingly digital and data-driven. Today, these products are moving from a single physical reality to one that includes the digital dimension, where online and offline realities are interrelated, interdependent, and complementary at the same time. The reason is that production processes are becoming increasingly digitized, so it is important to understand what quality issues can affect them, as well as production processes.

Because of the above, it must be understood that digital quality management consists of applying new technologies to quality management, both at the technical and human level, where related jobs are developed in increasingly connected and data-driven environments. However, it turns out that digital transformation accelerates the arrival of digital products that undoubtedly impact quality. This is the case of IoT products linked in a network and able to interact with each other and with a centralized system, which allows them to support higher levels of quality assurance because they integrate and validate the different parts and components of the system [15].

In all this, it should not be forgotten that the digital transformation and greater use of new technologies allow greater integration between Systems Engineering and quality [16]. The former is concerned with developing higher-level products and projects while promoting integration between different business areas, which is necessary for the process of digital transformation with a vision of quality. It can then be pointed out that quality is a basic aspect when thinking about digital transformation because it should not only be aimed at using technology but also at the aspects that will be impacted by new technologies, including quality management.

4. SUSTAINABLE DIGITAL TRANSFORMATION

Since the late 1980s, societies have seen the emergence of the so-called digital revolution that has transformed the economy, culture, and the different ways in which humans relate and coexist. First came the connected economy characterized by the Internet; then came the digital economy for the supply of goods and services, in which business models were based on the use of digital platforms; and since the beginning of the new century, the digitalized economy has appeared, with production and consumption models based on the incorporation of new technologies in practically all economic, social and environmental dimensions. Reaching the current level of adoption and integration of advanced digital technologies, societies are moving from a hyperconnected world to a digitized New World Order [3].

This world is characterized by merging the organizational, productive, and governance systems of the traditional economy with the innovative characteristics and business, production, business organization, and governance models of the digital economy. This generates a new digitally intertwined system, where models from both spheres interact, giving rise to complex systems in continuous organizational, institutional, and regulatory transformation. Both dimensions of development are constantly evolving but united in a synergistic process that inevitably affects the different social, business, and state activities [17]. That is why digital transformation is a dynamic and complex process that challenges existing rules and policies while adapting to organizations through a systemic approach.

As far as the productive sector is concerned, digital transformation takes the form of new management, business, and production models, to facilitate innovation and access to new markets, while revolutionizing the traditional industry. The use and incorporation of new developments in connectivity, intelligent systems, virtual value chains, and artificial intelligence in production processes greatly help to accelerate innovation, generating greater productive utility as well as growth in economic reactivation. In addition, smart production models create greater competitiveness in the global arena and a reduced environmental footprint, as companies modify their production processes with more planet-friendly standards. This is provided that the digital transformation is structured and implemented based on rigorous studies and smart decisions, because, otherwise, it could generate problems of inclusion and sustainability, forcing patterns of social exclusion and unsustainable exploitation and production practices [18]. Therefore, a well-thought-out and executed digitalization contributes to the dimensions of sustainable development: growth, equality, and sustainability, but its net impact depends on the way it is adopted and implemented.

Currently, due to the economic and social crisis generated by the pandemic, companies have had to accelerate many of the aforementioned changes, since the priority was to maintain a level of activity that would allow them to remain in the market. This accelerated incorporation of digital transformation seems irreversible in the context of economic recovery, the reason being that the pandemic made the need to reduce the digital divide and the importance of new technologies more visible. The point is that the digital transformation should not be structured and incorporated thinking only in terms of achieving an adjusted reactivation, but to build a new business context through economic growth, employment generation, inequality reduction, and greater sustainability.

The needs generated amid the pandemic made visible the benefits of using digital technologies, in the economic, social, and educational spheres. But they also showed that these benefits were not available to all individuals, companies, and educational institutions, because countries have not yet solved the problems related to gaps in access to and use of new technologies.

In addition, it made visible a reality that has always been kept hidden by the administrations in power: the need for an education system *that trains people and trains professionals* [19], because current workers have barely adapted to the new labor context, and with unimaginable difficulties. These gaps in access, use, and lack of skills for people to feel included in an increasingly digitized world are issues that a digital transformation program must anticipate and address to be successful.

Another issue to take into account is that in the New World Order, digital skills are becoming more important, not only for work but also for social life and professional training. In this context, people not only need traditional technical skills, but also to be able to understand and interact with media, search for and use information, be critical about what they find, and use various ways of communicating appropriately [20].

However, it turns out that many of the new technologies are intended and developed to be used in countries that have sufficient infrastructure and resources, so developing countries need, even if they cannot acquire these technologies, to get professionals to develop sufficient skills to work remotely anywhere in the world. Such skills can be thought of at levels of:

1. *Adoption*: basic education, literacy, and familiarity with devices.
2. *Basic use*: understanding of new technologies, knowledge of digital rights, privacy and security, and the ability to use them collaboratively.
3. *Creative use and adaptation*: basic computer skills and familiarity with algorithms.
4. *Creation of new technologies*: sophisticated programming skills and knowledge of complex algorithms.

So, those countries where technological development is just in the early stages need their professionals to develop basic technical and generic skills; but in countries where manufacturing is driving development, workers need to develop specialized skills in issues related to new technologies. The reality is that most countries don't seem to know what stage they are at, which confuses employers, but, in any case, they should recognize that much of the learning needed in Industry 4.0 is achieved on the job, either through experience interacting with technology or through retraining programs. The development of these skills is part of a process in the structuring and implementation of digital transformation, where it is imperative to build and strengthen innovation systems to develop or enhance the productive capabilities of employees.

Due to these differences in the development of countries and the fact that the productive sector operates at different speeds and with little linkage between industries, it is also necessary to take into account and analyze the importance of a series of factors that enable or limit digital transformation. In this time of economic recovery after the pandemic, companies recognize the need to incorporate innovative production tools in their different processes, although many want to do so without conducting the necessary studies. Others simply argue that their initiatives in this regard are limited by barriers such as lack of financial resources, infrastructure, adequate equipment, and little or no capacity of their employees about new technologies. In any case, in the process of digital transformation, all companies will encounter factors that facilitate or limit digital transformation (Figure 2), which vary significantly in importance according to how and at what stage they are.

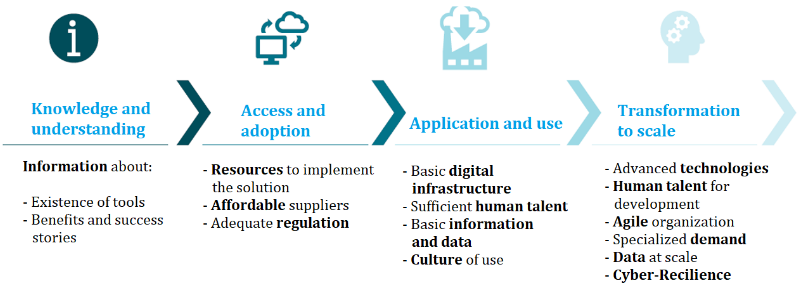

Figure 2. Factors that facilitate or limit digital transformation [21]

1. *Knowledge and understanding*: the first thing that every company must do is to recognize the importance of digital transformation, but many fail to do so, especially when they need to adopt new technologies identified in very sensitive areas. On the other hand, companies that are just starting with the idea of initiating the transformation, seem to worry little about finding the necessary information and knowledge about the new technologies, the benefits, or the need for the business.

2. *Access and adoption*: Once companies recognize and understand the need to initiate digital transformation, they must be sure they have adequate resources to access a solution. This includes financing to acquire it, access to suppliers, and a regulatory framework that facilitates the transaction.

3. *Implementation and use*: access to a solution is not enough to create value, because it is also necessary to have trained human resources to take advantage of new technologies in the business model. This means having the basic equipment, implementation skills, a minimum set of digitized data, and an organizational culture conducive to adopting the solution.

4. *Transformation at scale*: Many companies start the digitalization process, but few manage to take advantage of its full potential. The reason is that digital transformation at scale requires a

series of internal and external conditions that are generally only seen in digital native companies or in those that started the process in a structured way until an adequate strategy was found. That is why it is necessary to have state-of-the-art infrastructure and equipment; human talent trained to implement new technologies, while at the same time designing and adapting solutions to the needs of the business model; an agile digital culture that does not hinder the emergence and materialization of ideas; in addition to having developed the necessary cybersecurity to protect the information and prevent and mitigate cyber-attacks.

5. CONCLUSIONS

The accelerated technological change that humanity has been experiencing since the beginning of the century has reshaped economies and societies all over the planet, although in many countries, as in previous revolutions, the real representation of change will take time to be seen. But it is safe to say that the changes will be more impactful as we move into the next decade and will affect all dimensions of human development. To ensure that these changes do not have a major impact, governments, businesses, universities, and society, in general, must prepare themselves to face these problems. The goal is that all nations can participate in the New World Order and benefit from the new technologies, albeit at the same level, but not be left behind, as has been the case since the First Industrial Revolution.

No government can know a priori how new technologies will impact its development, but it can prepare and shape the path that offers the best results for its economy and inhabitants. That is why they must structure appropriate IT policies to advance digital transformation processes, regardless of the stage of development they are in. Some will require more or less effort than others: for some, it will mean acquiring and massifying cutting-edge technologies, making the most of them to diversify their economies, improve their education system, and offer their inhabitants better communication options, but others will need to make a deep commitment to the development of these technologies. In any case, all countries will need to educate and train their people and businesses to learn how to survive in an era of rapid change.

The impacts of the digital revolution on businesses became more visible and intensified in the wake of the pandemic, revealing their shortcomings in the face of the reality of the New World Order. As evidenced around the world, the remote provision of services in education, health, and commerce, as well as telework and social relations, increased and permeated most of society, although to different degrees and levels in countries where the new technologies are still entering or are just beginning to be recognized.

However, despite the benefits of digitalization, the growing development of new technologies has also increased the intensive patterns of energy and raw material use, increasing the generation of greenhouse gases and solid waste. That is why a process of technological transformation must be structured to take advantage of the former and reduce the latter, which means changing the pattern of digital development and putting it on a path of inclusion and sustainability.

The point is that such a process is not automatically incorporated into the new technologies and, to set it in motion, all economic, social, cultural, and educational sectors must be involved. In any case, digital transformation must become a major boost to economic reactivation and sustainability but always adjusted to a progressive structural change that encourages the adoption of new technologies in the productive sector, while at the same time universalizing them and taking advantage of them to develop in professionals the necessary skills for adequate performance in the New World Order. The final result will depend on how strategies, policies, and actions are implemented in the process, but bearing in mind sustainable development.

In any case, new technologies, whether through institutions, networks, or social norms, often amplify human capabilities and magnify existing social forces, but ultimately the impacts will depend on how societies respond and, in particular, the extent to which they have an impact on economic revival, which can help steer technological development toward sustainable outcomes.

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II

How do organizations successfully structure, implement, and sustain a digital transformation process without a leader to drive it? A study on the emergence of distributed leadership

Different studies describe the digital transformation process as strategic and rational, in which the roles of the different actors are clearly defined and where the presence of the change management leader is essential for its successful completion. In this research, ethnographic fieldwork with participant and non-participant roles of the researchers, evidence was found that it is a less rational and more emergent process that, to be successful, does not require centralized leadership. The reason is that digital transformation can be managed through the joint actions of several people and by working as a team, i.e., through distributed leadership. According to the findings of this study it can be stated that digital transformation is a holistic process, in which distributed leadership is essential to achieve a successful implementation.

1. INTRODUCTION

The process of digitalization and its outcomes, generally known as *digital transformation* [1, 2], is one of the topics with the most discussions and debates in business research and groups of business advisors and scholars in the 21st century. The conclusion for most specialists is that digitalization and transformation are a global megatrend that innovates, especially value chains [3], or a driver of societal development in this century [4], but as a research topic, it has only recently aroused the interest of researchers and almost always from the perspective of critical management.

This generates difficulties for research since it is still not possible to find a unilateral understanding of the subject, but what they do seem to agree on is that it is a fundamental challenge for exercising leadership in organizations [5]. Given this perspective, research has begun to address the issue from the figure of leadership in the management of digital transformation, and different visions, but it is not yet possible to speak of a real understanding.

Although at the end of the last century, an attempt was made to describe digital transformation as a mirage without much of a future, today it cannot be denied that its adoption implies remodeling the context, the business model, and the structure of organizations [6]. This implies an alteration in the concept of the practice and theory of leadership about the skills, abilities, and capabilities that a leader must develop to achieve the successful implementation of this transformation. The point is that before there was a shortage of good leaders in organizations, who were real drivers of performance, productivity, and change, in the New Era it seems more difficult to find those who lead organizations to a real and adequate digital transformation [7].

According to Klus and Müller [8] the leadership skills for successful digital transformation are: 1) creating a transformative digital vision, 2) empowering people through engagement, 3) focusing on digital governance, and 4) building technology leadership. The first two do not need much explanation, as they are recognized as leadership capabilities, but digital governance and building technology leadership are novel. From the perspective of the New Organizational Age, the leader must be able to direct digital activities toward a strategic vision that will allow the organization to remain competitive in globalization.

The situation that society has been experiencing since the beginning of the century, in terms of the continuous emergence of technologies and developments, has led organizations to prioritize digital transformation in response to the demands of consumers and customers [9]. A change in the management structure that some describe as a process of implementing and using new technologies, to innovate production and improve the business model, which every leader must be able to manage [10, 11].

But the reality is different because digital transformation is a complex challenge in which all systems and administrative and productive structures must be involved, to ensure that new technologies are aligned with the objectives of the organization, and its processes benefit to redefine the value proposition; which implies creating a new organizational identity [5].

The common alternative adopted in the face of this challenge is to create a *transformation office* and appoint or hire a *leader* for it [5, 6]. This has made these leaders become a determining factor for the achievement of digital transformation, i.e., a kind of change agent for organizations. Therefore, it is expected that, for the implementation and implementation of such transformation, the leader structures and manages initiatives and new practices to make the most of new technologies, but, substantially, to achieve a close and productive merger between business functions and Information Technology IT [9].

This is the common equation that organizations implement to introduce new technologies into their business model, but little is known about what happens when, for some reason, the *leading* actor is removed from the equation. The objective of this research focuses precisely on trying to answer the question: *how do organizations successfully structure, implement, and sustain a digital transformation process without a leader to drive it*? And, contrary to what many authors and specialists on the subject of digital transformation claim, the process is successful even without a leader in charge.

Something that most specialists and people involved in business management agree on is that digital transformation is a strategic process, which requires new skills and planning to implement and use new technologies in organizations [12-14]. A decisive factor in this process is the leader of the transformation office, who is most often hired temporarily, and whose task is to structure and implement the digital transformation, making him or her an important person for the organization. This situation led to the position of digital transformation leader being the most in-demand in the last decade [15, 16].

Due to this is that in the literature it is considered that this leader is important for the achievement of any transformation [8, 10], so it is expected that companies structure the position with clear roles and responsibilities.

Then, this change agent is characterized as a person who must provide sufficient justifications to demonstrate that the adoption of change is suitable and rational, predispose the organization for change and achieve the acceptance and participation of human resources, and implement the change in the optimal time and with the optimal resources [16].

Based on the above, it could be stated that this leader is a change agent responsible for the implementation of new technologies, and structuring a process that must radically modify the organization's systems. But, even if all possible expectations are placed on this leader, in some situations he is dismissed, so the transformation office team and the company's management must assume these responsibilities and manage the digital transformation process.

This situation is what originates the question of this research and, to answer it, the researchers relied on *distributed leadership*, a framework in which leadership is recognized as a less strategic, less fixed, and more emergent and shared issue [17, 18]. A contribution of this study to the literature is that it analyzes the role of management in the process of digital transformation, something that is understudied because the role of the change manager leader is taken for granted and because it has almost always been examined only in strategic change in general [9].

Distributed leadership is a research topic that has attracted attention since the turn of the century, and Bolden [19] concludes that it is a potential solution to the tendency of leadership thinking to split into two camps: 1) to view it as a consequence of the actions of individual agents, and 2) to view it as the result of systems design.

In this same line some suggest that, because of the demands on organizations in the New Era, the concept of leadership needs to be reformulated, because in the new context, it is more appropriate to conceive it as dynamic rather than static [20, 21], as a collective social process that emerges through multiple interactions [22], and as a group activity that works through and within relationships [23]. Others propose designations aimed at reformulating the concept of leadership, such as shared leadership [24], collective leadership [25], collaborative leadership [26], co-leadership [27], and emergent leadership [28].

The concept of *distributed leadership* is used in this study because the previous proposals underlie the need to understand leadership as a collective and social process, and also because leading is conceived as an activity that builds leadership through a relational process. Here, relationships are understood as the core on which leadership occurs, and where emergent communication and movements in favor of leadership coexist. In any case, from this perspective, it is also necessary to balance the collection between people and the practical situation of leadership, so it is studied how relationships are developed at the same time as the construction of individual leadership of the administration, which allows understanding why leadership is distributed.

This approach appreciates how leadership is distributed in contextually situated situations and how distributed and focused leadership interact, as the show is only part of the context. This research describes how and why leadership practice is distributed since the objective is to find an answer to the guiding question in the context of digital transformation. So, starting from the concept of *distributed leadership* as a theoretical basis, this question is complemented by two questions: how and why does management build distributed leadership? What is the influence of the digital transformation process on leadership?

2. METHOD

It explores empirically and interpretively how digital transformation can be successful without the leadership of a change agent. This type of research was selected because interpretive research helps researchers to understand and comprehend human thought and action in different social contexts; moreover, it offers the ability to generate broad knowledge about the phenomena of Information Systems and Technologies [29]. The research process was carried out in two stages: 1) ethnographic fieldwork, to observe the organization's administration in terms of how it builds leadership, and 2) interviews with members of the administration.

A Colombian organization in the banking area collaborated in the study by hiring a temporary consultant for the structuring and implementation of new technologies. Since no progress was made on this objective after five months, the management decided to dispense with his services but did not replace him with another leader to carry out the task.

In the contextualized exploration, an analysis was conducted on how distributed leadership helps to realize digital transformation in a process without a leader as a change agent. To explore how management builds distributed leadership during digital transformation and its consequences for the process, the emerging communication between the team and how they conduct their relationships were taken into account [30].

At this point in the research, a detailed ethnographic study of leadership practices and discourses in the context was needed, a method that allowed the researchers to understand what happens inside the organization in the process of digital transformation. This provided first-hand access to the management's reasoning on the selection and implementation of new technologies, as well as to the daily work activities carried out by its members, which allowed the researchers to understand and comprehend how digital transformation is managed in a team that does not have a leader.

For the interviews and to analyze, discuss, and understand the effects of digital transformation on leadership, the qualitative research method is selected [31], but due to seeking a deeper understanding of these effects, the critical reflection approach is chosen, because it offers greater exploration and a deeper insight into the responses of managers regarding their view of digital transformation, and the effects on themselves and their leadership.

2.1 Capture of information

The ethnographic observation began one month before the organization decided to hire the leader, was extended during the time he was developing his leadership functions (five months), and six more months after he was dismissed and the role of leader was removed from the process. The interviews were conducted through a follow-up seminar with the members of the administration in the month following the completion of the digital transformation process. Empirical data are collected through ethnographic recordings by the participant and non-participant observation during management meetings, both before, during, and after the leader.

Among the data captured are: how communications are organized with personnel involved in the digital transformation process and how they adjust them according to the results; management's reflections on the required strategies and how they decide which activity or activities to carry out to achieve the objectives; how discussions are held about the functionalities of the new technology about the mission and business model, and how to implement it. The data are essentially ethnographic field notes taken at the meetings, to which notes with complementary reflections are added. In the content are verbatim summaries of the discussions and conversations, including direct quotes, as well as interpretations of the emotions exhibited and personal annotations by the observer. The purpose of these notes is to capture the researcher's fieldwork experience and to gather reference points for later analysis.

Ten structured interviews were conducted with leading area managers, with an average duration of 45 minutes, and structured in three aspects: 1) conception of digital transformation, 2) effects of the digital transformation process on leadership, and 3) how to lead digital transformation. The characteristics taken into account to select the interviewees were: academic background, experience in transformation processes, and knowledge of new technologies; in addition, and in order not to lose the researcher's objectivity, aspects such as demographics, cultural level, and work department also played a role. To maintain an adequate ethical level in the research, each interviewee was informed of the content of the questions and was asked to sign the informed consent, therefore, no physical or personal harm was generated and the principles of research ethics were respected.

2.2 Information analysis

To carry out the analysis in the research, and taking into account the knowledge about the empirical context of this study, deviations are sought from what is expected to be found through the methodology of Alvesson and Kärreman [32], given that, as the authors state, *empirical information is an inspiration for critical dialogues between theoretical frameworks and empirical work.* Moreover, ethnography can be conceived as a process of coherent resolution of ruptures (Table 1).

In this study, the researchers familiarized themselves with the context by acting as participant and non-participant observers for 12 months in the organization. Six months into this ethnographic fieldwork, a deviation was identified: *management fired the change agent leader*. But while the researchers had *a priori* knowledge of what a digital transformation process entails, this deviation created a mystery to be solved: management continued the process and eliminated the leader position, but they seemed to intuitively share responsibility for managing the process without losing sight of the mission objectives.

Table 1. The methodology used for the analysis of the information [32]

Steps	Definition	Description
1	Be familiar with the environment and ask open-ended questions.	Based on prior decisions about a field of interest and a broad initial focus for the research.
2	Identify/construct deviances in the understanding of the environment.	Fieldwork must be grounded in theory, but also sufficiently varied and rich in the sense that it allows for the existence and exploration of deviations.
3	Formulate preliminary interpretations of the theoretical contribution based on its relevance.	After encountering an unexpected deviation, the researcher formulates preliminary interpretations.
4	Conduct systematic work to develop a new understanding of the deviation.	Additional resources are used, such as philosophy and social theory.
5	Resolve or reformulate the deviation.	By developing a new idea that offers a new interpretation of the phenomenon that generated the deviation.
6	Develop deviation resolution.	To make it more broadly relevant to the specific field and to position it more clearly about other theories.

Contrary to what can be found in the literature about digital transformation, the process in this organization developed less strategically and more rationally, while being more emergent and fluid. This caused the researchers to keep their minds open to the empirical information they found, albeit reflecting on what the theory related to digital transformation and the role of the leader as a change agent asserts. By that time the mystery has taken shape and can be concretized to *how and why digital transformation continues successfully without the presence of a leader*. Then the compendium is made between the collected empirical information and the related theory, expanding the knowledge of the researchers to solve the mystery.

On the other hand, given that the objective of the interviews is to analyze, discuss, and understand the effects of digital transformation in management, the information is taken from the theories of the literature to test and confirm it with the empirical information from the ethnographic fieldwork.

3. RESULTS

3.1 Ethnographic fieldwork

Although initially, the research question driving this study was: *how do organizations successfully structure, implement, and sustain a digital transformation process without a leader to drive it*, *how and why does management build distributed leadership,* and *what is its influence on the digital transformation process?* It was found that, intuitively, the team decided to share the responsibilities and activities of the digital transformation process. In addition, by reorienting their relationships, they learn to build effective communications, manage to accept and discuss individual points of view in favor of the common goal, and find shared appreciations and responsibilities, thus materializing distributed leadership throughout the process.

3.1.1 First contact

In the first meetings of the management team, it seems that there are no points of agreement about the new technology to be implemented; they intuitively overlook the opinions and appreciations of others, which is found in the theory about distributed leadership, and make their positions clear. The technology to be implemented is an Automated Advisor for the organization and innovation that arouses enthusiasm among the CEO and the Marketing Director because they envision ample possibilities for development and competitive advantages about the demands of the New Era and the bank's customers. On the other hand, the Sales Director is concerned because the human advisors are not trained to obtain the greatest benefits from the new technology; then the CEO suggests that they should be trained to develop the necessary skills, and that from now on the human resources that have already developed them should be hired.

On the other hand, the Operations Director sees no problems in this regard, because the human advisors simply have to adapt to the new technology. There is a serious communication problem since for him this change cannot even be seen as an innovation for the organization because what is being acquired is just another tool.

The Human Resources Director is concerned about the organizational culture at all levels and agrees with the CEO in terms of training human resources consultants to take advantage of the new technology. He believes that this innovation will have an impact on the employees of the department directly involved, but also on the rest of the organization, because it changes the way human resources consultants work and their product, and because it will necessarily create new administrative positions.

Since the researchers are participant observers in the ethnographic fieldwork, they ask the management team how the Human Advisors conceive of the Automated Advisor: as a tool, as another advisor, or as a supervisor. For the Director of Operations, the answer is clear: as a tool; while the Director of Human Resources notes a problem here because so far the finance department staff has not been presented with a clear description of the role of the Automated Advisor. The Director of Operations maintains that this issue is a Byzantine discussion since it is not necessary that, at this stage of the process, they are well aware of the functions of the new technology.

For his part, the Director of Communications expresses his concern about the communication challenge that this generates; while the General Manager, who has so far remained on the sidelines, gives importance to the discussion on the implementation of the new technology, which he describes as a link between the organization's strategy and mission objectives. He states that for most of them, the issue is new, so they may have no idea how to carry it out, and the more they think about how to do it, the more confusing it is for them. But, although it is difficult to define, they cannot stop here, because the organization comes first and the objective must be to keep it in the market, so he invites them to continue with the analysis, meetings, discussions, and teamwork.

In the end, they do not answer the researchers' question precisely, but the discussion that is generated around this point allows us to know more broadly the opinions and individual points of view of the team. At first glance, this may be a manifestation of dispersed leadership that does not facilitate the necessary communion towards the achievement of digital transformation, but a dominant position is not identified, a characteristic that facilitates the emergence of distributed leadership to make up for the lack of the change agent leader.

3.1.2 Second contact

As in most organizations, management meets frequently, both formally and informally, and while there is broad participation, it is expected that participants will not always agree. This is part of the dynamics of a group of people working together and is necessary for organizations to analyze diverse points of view before making decisions. Thus, researchers note that management has developed a culture of communication that is an intrinsic part of its responsibilities. In this way, they develop a broad vision of the topic under discussion, as it happens in this ethnographic fieldwork in which, from individual appreciations, arguments, and functions, the team can reach a common point of view on the new technology to be implemented.

However, although they have not yet fully assimilated all the arguments of the others, they already have a better understanding of the digital transformation process, because they complement their ideas with the insights and concerns of the others. Although it is expected that in these processes the administrations talk frequently and that the objective is always focused on the materialization of the process, in this case, the meetings do not take place constantly, leaving a lapse of time for each participant to analyze the opinions of the others and complement their own about the digital transformation with additional readings and consultations. It cannot be said with certainty that distributed leadership emerges sporadically from these meetings, and the reason is that they are not yet strategically planned and are spontaneous and intuitive.

3.1.3 Third contact

As observed in this study and according to related literature, distributed leadership does not replace individual leadership, nor do managers agree on joint leadership. The observations carried out in this study show that distributed leadership is based on permanent communication and objective relationships.

The CEO invites the others to think about why they are part of management and presents their view on the matter with the argument that the reason for this is because they express themselves without fear. The point is that in the organization management is not pyramidal but horizontal and the management team does not work around hierarchies, i.e., top-down.

In the meetings, there is respect, trust, and support, as evidenced in the interviews, where positive opinions are heard from each other. In addition, because of the functions of each person and the departments they manage, it is common for them to meet with each other separately, creating close relationships that lead to informed decision-making.

These types of relationships are not strategic or planned and are not described among their functions, but by properly understanding the objectives and mission of the organization, they are developed almost automatically to keep the organization productive and competitive in its environment. It is there where it is found that in these practices and within the organizational culture, distributed leadership is institutionalized, giving way to coordinated actions that lead to managed change, as in the case of digital transformation.

3.2 Interviews

The interviews are structured to understand in-depth the effects of a process, such as digital transformation, on the emergence of distributed leadership in a team. After the ethnographic fieldwork, the researchers exclude many of the concepts and insights found in the literature on the practice of leadership in general, focusing their analysis on the form of distributed leadership and trying to identify, based on the responses, the effects that can be attributed to the process of digital transformation on it.

3.2.1 Concept of digital transformation

Shifting positions on digital transformation were heard, as skeptics took on the task of seeking information about it to better contribute to its implementation. They spoke of the broader macroeconomic effects associated with new technologies and that they have changed organizations and societies around the world in the New Era, which are seen in disruptive and transformational changes, both individually and organizationally.

For some, digital transformation is a psychological, change-driving, disruptive, and transformative process that impacts organizations and their environment, aligned with strategic, social, organizational, technological, or regulatory changes and trends. Therefore, leadership must be influenced by all these aspects that emanate from the digital transformation process. Because digital transformation is disruptive and offers a unique opportunity for achievement in a short time and in a harmonious way, it is even considered an enabler for achieving changes in human behavior, which is also seen in the social, technological, and educational spheres. However, most are concerned about its effects on leadership, as well as its long-term impact on organizations, society, and individuals.

3.2.2 Effects of the process of digital transformation on leadership

In addition to recognizing the concept developed by the leaders after the ethnographic fieldwork, the interview also focuses on listening to their perceptions about how the digital transformation process affects leadership. The interviewees state that their leadership is based on characteristics such as values, transformations, and authenticity, which are part of the daily practices in their area. However, this is already known to the researchers due to their participation as participant and non-participant observers in the ethnographic fieldwork, so these practices are obvious and have been internalized by management.

But after their experience in the digital transformation process, working with their peers, they describe a series of aspects and characteristics of individual leadership that were significantly affected, and that most of them are consequential for the emergence of distributed leadership:

1. *Trustworthiness*. All interviewees agreed that their leadership was recognized in each department, in addition to the fact that they had the trust of management and employees. However, trust in the leader is affected by the digital transformation, because it must also be earned by using and leveraging new technologies to exercise leadership. In addition to the fact that trust is built on a mutual basis, they believe that employees must trust that if they have problems with new technologies, they always have a leader who can help them. This creates a kind of equality in every operational situation, where there is no leader and the leader, but a team that works together to contribute to the achievement of the mission objectives.

2. *Integrity*. Most agreed that in the experience of working as a team during the digital transformation they were faced with new integrity challenges. Among the reasons they wielded were statements such as that technology is not a problem for humanity in this century, but rather it is man himself for the inadequate use he makes of it. This made them question their leadership from the potential of new technologies and the utility given to them in organizations, so they argue that their integrity is reinforced and highlighted by the digital transformation from aspects such as interconnection, transparency, and decision-making. And the reason is that in the New Era leadership is strengthened integrally because of interconnected technology, so it must be exercised transparently, with vision and values.

3. *Attend*. A good leader must be present and listen to the staff he or she leads, a characteristic that interviewees consider a basic mechanism of leadership, but the digital transformation makes it become a standard, because now the presence, in addition to physical, can be virtual, anytime, anywhere. This ubiquity has meant that the leader has to learn to listen and respond to demands and recommendations, both from below and above his or her position. Leading amid digitalization requires leaders to develop the ability to listen, understand, and manage the abundance of information and to adapt to the complex context in which organizations coexist in the New Era.

4. *Respect*. For the interviewees, a leader must be a person who knows how to listen and teach, which is achieved with self-respect and respect for others. Those being led must first be empowered and then encouraged to move forward, appropriating values and delegating functions so that they feel they have the courage to contribute and build. For some, giving respect is a two-way street, because you also earn it, but you also learn that leadership is distributed and does not rely on one person. You have to listen to all initiatives so that people can contribute ideas and create distributed leadership for the benefit of the organization. Respect for the leader is affected by the digital transformation in the sense that in digital teams it is always necessary to yield, and access new technologies and those who have greater management of them, so that power is diffused in joint and common actions.

3.2.3 How to lead in digital transformation

About this aspect, in the interviews, we inquired about the assessments, after the fieldwork experience, on how to be a leader in digital transformation, and the answers revolved around the following topics.

1. Leadership in digital transformation has to be holistic because it is necessary to understand and comprehend the global perspective of the impact of new technologies on the organization. For most, in the New Era, it is crucial that the leader has a global vision of the problem and not limit his role to executive decision-making, because he must be attentive to the details and involve the internal and external perspectives around the digital transformation, whether from the personal, organizational and the rest of the work team while involving the micro and macro trends that may affect the achievement of missional objectives. This is aligned with the observations they offered on the effects of digital transformation on leadership since the process requires the leader to be able to navigate and manage them, to find the way forward in each case. That is why in digital transformation the leader cannot only exercise general leadership, but accept his or her shortcomings in the process and empower the team to intervene, and in this way, a distributed leadership emerges, which leads to the process developing successfully.

2. In the New Era, where organizations are beginning to give up their physical positioning in favor of the virtual one, the leadership perspective is forced to do the same. In digital transformation, the leader must orient his speech, actions, and decisions to people who observe him, watch him, and contact him virtually. Therefore, he must lead through digital communication, strengthening his presence and profile, building, merging, and creating a strong virtual identity as solid as the physical one. Interviewees believe that by demonstrating leadership capabilities in the digital realm, you also enhance aspects of personal value with a transformational and authentic leadership style. Amid digital transformation, it is learned that digital channels do not limit the audience, and leadership has greater coverage, thus surpassing physical leadership aimed at a limited number of people in mobility and agility.

3. As the digital transformation process unfolds in the organization, the area leaders realized that they could manage their leadership in the middle of a network. This is because they engaged in replicating how they conduct analysis and discussions, and how they reach agreements in their management roles. Some mentioned that they first discuss with their department and then bring the conclusions to work with the management team. This allows them to create a network-based leadership perspective, i.e., from small, controlled hubs, which coalesce and move forward through knowledge sharing. This type of leadership amid digital transformation allows them to quickly find transdisciplinary solutions, thereby extending distributed leadership in working with the other administrative staff.

4. DISCUSSION

After the dismissal of the change agent leader, the management, through emerging relationships and communication activities, manages the digital transformation process intuitively. The results confirm what has been found in the literature about strategic change [9], as the transdisciplinary expertise of managers influences the change and implementation of new technology to be achieved. In addition, the empirical results of the ethnographic fieldwork reaffirm the benefit that digital transformation achieves when these individual experiences are shared with the team.

This becomes a finding that challenges what is known about digital transformation, because it demonstrates that without a leader change manager, it is possible to achieve success in this transformation, differently from what is argued in the literature for functionalist and planned processes. The empirical results question the need for leaders in organizations because if the management team joins efforts, experiences, and knowledge, distributed leadership arises sporadically and processes can be carried out. In any case, this generates a deeper reflection about whether organizations need a change agent, and while in the literature the answer seems to be both yes and no, it appears that with distributed leadership it is also possible to achieve success in change management and digital transformation.

However, this is not the case for every type of organization, because several factors must come together for the process to be successful. In the ethnographic fieldwork of this research, it is evident that the administration is always willing and intuitively shares knowledge and experiences, while drawing common lines of linear communication, without the positions interfering. Everyone assumes their role with responsibility and does not delegate the functions to be developed in the process of digital transformation.

This scenario, in which the organization has a culture of communication and participation in discussions and analysis, in which they don't need to agree, gives rise to an intuitive and holistic understanding of the meaning and importance of digital transformation, which undermines the need for a leader to manage change. But in any case, it is necessary to continue researching digital transformation processes without a leader, in different organizations and administrations with different types of cultures, to complete the picture that reflects how and if administrations play the role of leader when, for some circumstances, this role is not hired or is suppressed.

Another finding in this study is that research on distributed leadership has been conducted mostly in school settings [33], so it is possible that it is not always the most indicated to best manage digital transformation processes, and that more studies are needed in this regard. On the other hand, not all studies find that distributed leadership has positive effects on change management and, on the contrary, that it generates negative effects [34, 35], but other scholars find potential benefits when implemented carefully [36].

Therefore, the objective of this research is not to tell administrations what to do in the face of a digital transformation process without a change management leader, on the contrary, it is only intended to describe a less rational process, but a more emergent and fluid than what is found in the related literature. Furthermore, it is recommended to continue studies to explore the need or not of a leader in digital transformation, but observing it as an emergent process with distributed leadership.

One of the important contributions of this research refers to the results of the interviews because substantial knowledge was found to understand the effects of the process of digital transformation on leadership, and how to lead in digital transformation, which, its effect on leadership, contributes to knowledge to the little researched interaction between leadership and digital transformation. In this regard, it was found that the process has a non-reversible social effect, generating attitudinal changes, and enabling and creating new forms of communication, leadership, and culture among people. Consequently, it is expected that this study will be reviewed and corrected with caution because it is necessary to critically test the assumptions, validity, and relevance of the results.

5. CONCLUSIONS

This research contributes to the body of knowledge on digital transformation, the change manager leader, and distributed leadership, with application and analysis in ethnographic fieldwork of more than a year, in which experiences with an administrative team in a financial organization, and how they managed and implemented the digital transformation when the leader of the process was left without.

Unlike what can be found in the literature on digital transformation, where it is described as a rational and strategic process with a precise role for the change manager leader, in this study the findings show a different reality. The reason is that we found a team that works from collective actions to manage an emerging process through joint leadership and intuitive commitment, in which individualities were overcome by a mobilization towards change from consensual perspectives.

Another important feature that was found is that managers are not synchronized, as detailed in studies of distributed leadership, but exercise management from their points of view and experiences. A situation that facilitated their active participation in the process through distributed leadership, was to find the holistic approach that led them to the success of the digital transformation. That is why in this research digital transformation is observed as a process for distributed leadership, and it is discovered that shared responsibility can replace the presence of a change manager leader in organizations with certain characteristics.

On the other hand, digital transformation has an essential effect on leadership for the New Era, due to characteristics such as interconnectedness, immediacy, an abundance of information, transparency and complexity, elimination of hierarchies and personal barriers, agility for decision making, and a clear humanizing effect. At the same time, it was found that managers internalize these effects and take advantage of them to improve distributed leadership. Therefore, it is concluded that, according to the results of this research, digital transformation changes the way managers exercise their leadership, from an individual to a team perspective.

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III

Define and use the term good/best practices in the complex context of the New World Order

The term *good/best practices* appears very often in literature and diverse disciplinary scenarios, such as marketing, however, despite how frequently it is used few discussions are found about its meaning and the reliable identification of good practices. This work is the result of a systematic review of the literature to verify whether is possible to find a general definition for this term. The final sample consisted of 126 works, from whose analysis we can conclude that there is not a common understanding of the meaning of this term that contributions are based on personal opinions, individual experiences, or anecdotal information, and not much is based on empirically detailed studies. Results determine that the definition of this expression is interpreted as experiences: 1) performed by most organizations, 2) applied only to successful organizations, 3) based on observation and experience, 4) based on opinions, or 5) based on empirical research.

1. INTRODUCTION

Generally, it is accepted that the term *good practices* emerged from both the interest of the industry and the implementation of benchmarking. The process began seriously in the decade of 1970s. It increased its popularity in the decade of 1980s when the companies became interested in discovering their assessment compared to their competitors and became interested in determining why some companies were more successful than others in specific fields. Today, benchmarking is defined as identifying the good practices related to products and processes, both inside and outside the companies, to use them as a guide and reference point to improve daily practices [1]. Correspondingly, good practice was defined as an experience that has demonstrated higher performance, and its adoption was considered as a mechanism for improving the performance of a process, a business unit, a product, a service, or an entire organization [2].

Therefore, is not surprising that nowadays the interest in *benchmarking* and the interest in good practices is not limited to the manufacturing sector because the term has entered the vocabulary of all disciplines and areas of knowledge. However, despite how frequently it is found in the literature, it is not possible to find a standard or even a meaning widely shared among those who have used it. Is evident that without a comprehension of its representation, there are some questions about how to give meaning to the literature corpus of good practices, and about what ideas can be deduced from it.

Apart from the definition problem, the biggest problem remains because there is no accepted solid evidence supporting the statement indicating that a method or process is a good practice. Which means can be used to establish what good practice is? A good practice is based on evidence or its foundations are as varied as the definitions of the term itself? The question is not merely academic, in the current political context that increasingly demands reports and measurable results, the attention must be focused on establishing significant ways for evaluating the performance and work must be done to get further coherence and clarity in this discourse.

Although we found a considerable amount of good practices in several disciplines and professions, ranging from liberal arts and humanities to engineering, there is relativity few articles exploring how to define what good practices are, particularly in the field of study and practice of organizational change where have been conducted more studies to establish the basis for its demand. For example, Reavy et al. [3] conducted a systematic review of the literature related to Evidence-Based Management EBMgt to answer three questions: 1) is there a considerable amount of literature related to this concept? 2) What is the evidence quality? 3) it can be demonstrated that organizational performance is improved? They reviewed 169 articles and they found that a great number of them deal with this subject, but most of them adopt EBMgt based only on opinion and anecdotal evidence.

It was surprising for them to find that there was little evidence indicating that production had improved. Hallencreutz and Turner [4] explored organizational change to establish if consistent models and definitions are used consistently to declare an exercise or process a good practice. They reviewed 160 works containing some combination of the terms *organizational change, change management,* and *good practice,* and they concluded that many of the popular management practices labeled as such are based on anecdotal evidence instead of empirical data. It is important to note that this work is based on a previous study in which the authors established that in the literature we cannot find coherent models or definitions regarding good practices in organizational change [5].

Simon [6] conducted a review of the literature about good practices in libraries in the United States and found that, although there are many related articles, most of them dealt with the importance of incorporating corporative evaluation and good practices in management; Simon also found that there is an evident lack of studies of cases that detail real experiences; and that no works are proposing a set of good practices being widely accepted by the community. Simon speculates that the reason for this lies in the work of theorists like Shera [7], Wasserman [8], and Lancaster and Joncich [9], who argue that a set of rules could not be developed for a specific discipline, because due to its nature they are not homogeneous and, therefore, they are not natural candidates or easy to normalize.

The aim of the study of Alias et al. [10], was to analyze the established criteria for good practices in project management based on the updates of the team leader. The main conclusions revealed that to achieve proper management, the head of the project must guide its capabilities in terms of knowledge, skills, and personal traits. Because by emphasizing them he could establish a new criterion for good practices. According to Giles and Cormican [11], there are strong factors of motivation for more efficient management practices that have been demonstrated to be one of the biggest differentiating attributes for success, however, in the literature, the term *good practices* is badly managed, in part because the specific studies of the industry are not enough, and consequently, there are few applicable guidelines. The study presents the results of an empirical analysis of case studies in which 66 works were collected.

There are other studies through a variety of disciplines that question the concept of good practices in a more general way, and normalized models and definitions are scarce [3, 12, 13]; and others that suggest models that could be used to evaluate and determine what is a good practice [5, 14]. In the field of health, there are some revisions to the results of empirical research [15-20], and in Computer Science there are also substantial contributions [21-25]. In the field of marketing, some propose good practices for corporations [26, 27], to impact people [28, 29] or propose operating guidelines [30]. While the complete exploration of these works through the spectrum of academic disciplines and other fields is beyond the scope of this work, other authors have already questioned these ideas and, of course, they conclude that more research is needed in this field to determine if any of the models or definitions suggested can be widely accepted.

2. METHOD

For conducting this systematic literature review the methodology proposed by Serna [31] was applied. In the process, three research questions were defined: What is understood in the literature for *practices and good practices?* What is the basis for presenting the definitions? Among which concepts can we classify the contributions? The review was conducted in the databases: ScienceDirect, ACM Digital Library, Scopus, and Web of Sciences. Because of the high number of articles found in a preliminary review, it was decided to search for the keywords (*Best practices, good practices, systematic review, and empirical studies*) only in the title and abstract.

With this method were compiled 950 works among articles, books, book chapters, proceeding works, and technical reports. The inclusion/exclusion criteria were applied to this population (results-oriented to define the terms and, a clear description of the type of study) to determine if the content contributes to answering the research questions and contributes to the achievement of the goals proposed in the review. At the end of this procedure, 185 works were collected and, after a quick reading of them and applying the concepts of quality for determining the value of each contribution in the research (proposing a supported definition, approaching the term from the experience, demonstrating its replicability), which resulted in a final sample of 126 works.

3. RESULTS

Much has been written about good practices in different fields and disciplines, but for this work, we only considered the contributions proposing or specifying a definition for this term. First, a classification was made by fields to group the contributions, which showed publications addressing the definition from the field of administration and organizations constituted the largest group of 53 works; then we have those addressing it based on engineering disciplines with 35; based on librarianship and information management we have 22; and finally, we have those based on other fields such as health, law, personnel management, and education, with 16 works. The results also confirm the fact that the term good practices has gained popularity in the discourse of different disciplines and fields of knowledge.

The works were classified according to the methods used by the authors to present a definition and fell into one of the following categories: 1) literature review, 2) practices derived from some field or discipline, 3) empirical research, 4) combined approach, 5) opinion and 6) other. Most of the documents of this sample are individual initiatives and have a disciplinary perspective, instead of a multidisciplinary or work team.

1. *Literature reviews.* In this sample, 20 works present non-systematic revisions to literature and they use this information to establish if a method or process is a good practice. Most people accept the definition because in the review they found the description of a method as a reference. Meanwhile [32] try to differentiate among the types of works they consulted and indicate that 23 works were identified as empirical works and 16 as opinion articles. This distinction is important for finding contributions with reliable content. The works they analyzed deal with a variety of subjects related to good practices, including education [24, 33-35]; customer service [22, 36, 37]; organization management [20, 38, 39]; information management [16, 40]; the provision of services [32, 41, 42]; the design [19, 43]; and document management [44, 45].

2. *Practices derived in some field or discipline.* Twenty-two authors chose this way to determine if a process or method can be considered a good practice. Some authors explain the system or method used in a field or discipline, they argue why they consider it works well, and, without prior or subsequent empirical evaluation they define what good practice is. This category includes, among others, education [35, 46-49]; organizational management [20, 50-52]; information management [16, 53-55]; Computer Sciences [21, 56, 57]; pedagogy [23, 58]; medicine [59, 60]; software engineering [25, 61]. Curiously, as with several documents based on literature reviews, in this category, some authors use the term good practices without any support, and none of them define the term.

3. *Empirical research.* This category is constituted of twenty works, and most of them involve questionnaires and surveys with answers collected through several online and printed means and interviews with specific people. An exception is the work of Stec [62], who performed pre and post-measurement of the learning obtained by students who completed the knowledge tests, both before and after training through good practices. The purpose of its study was to identify good practices in teaching through the evaluation of learning with different instructions and methods. Bittarelli and Rossi [35] use surveys to identify good practices in e-learning processes; Hodge [63] identifies those used by project managers; Cowen and Edson [64] apply questionnaires to find successful techniques in collaboration and communication. Shelton [65] performed a study about cooperative work by pre-selecting good practices that indicate

viability, registry, and longevity, and then they performed surveys about the conditions that made it easier or impeded cooperation.

Clair [66] and Singh and Holt [24] use the metadata of web content management systems and they apply a survey to determine content authorship, achieved workflow, found standards, and the obstacles to using metadata in context. Although the purpose, methodology, literature review, and result discussion provide useful information, pay little attention to information that allows evaluating the process as a good practice. In their works, Renner et al. [67] and Johnston [22] apply an online survey to determine how the services are provided remotely. Although the discussion of results searches relating to the established process in institutions, largely considers common practice as a good practice.

Butler [68] surveys requests, analyzes, and compares 12 descriptions of work in libraries, uses the results to describe the functions of the elements that should be included, and uses them to describe basic functions as good practices. However, similarly to many of the documents of this sample, practices are declared as good because they are common. Works based on surveys, interviews, and related methods are problematic due to the inherent partiality of research design. For example, surveyed people or participants in the survey generally are chosen because are in vanguard programs [15, 63]; or because they have a reputation for success [17, 65], but is not clear how is defined vanguard or success. Besides, common practices (that appear more frequently among those reported by the people who answered the survey) are simply translated as good practices without any type of rigorous analysis. A concern is that authors might select the answers they consider useful, and report them as good practices [64, 69].

4. *Combined approach.* This is a category in which authors use two or more methods to identify good practices, and that is represented by 34 works in this sample. The more frequently used approaches consisted of a review of the literature and a survey of different professionals [70-72], or a review of the literature and a description of the practices derived in some field or discipline [73, 74]. Other approaches include a combination of literature and document reviews (project reports, procedures, policies) [18, 75], an auto-evaluation along with a survey [11, 76], or a review of the literature, derived practices, and a study of the practices in a small number of institutions [77].

5. *Opinion.* Opinion articles are of two types: 1) those based on feelings or beliefs, and 2) those based, in part, on how are performed practices in a specific field or discipline. From the sample, 18 works are classified as an opinion, based on thinking or the author's personal opinions, and some works do not even cite any source [78-83].

6. *Others.* In this category 13 documents use a variety of approaches to identify and define good practices, or to discuss them as a general concept, but they are not among the analyzed groups. These include auto-studies, that is to say, comparing a common practice against the guidelines of the field or discipline [10, 84], discussions about what good practices are, questions related to adopting them, and the steps that could be followed to put them into practice [34, 85], or why good practices can help professionals and how to apply them [37, 86], another study the related politics [87, 88], and protocols and standards [57, 89].

In 10 of the 126 articles from the sample, a definition of the term practice or good practice is presented, in some articles, it is assumed as if were evident by itself; but in general terms, those that try to do it are far of a common or shared definition. Some assume them because of good results, standards made by associations or organizations, criteria derived through comparative evaluation, or from comparison to successful organizations, and appropriate standards for circumstances and practices that have proven good results. Some define them as those that fulfill federal regulations [82]; others are based on existing definitions [34, 88]; while Nelson [60], Loizidou, et al. [37], and Tarabah [45] create their own.

Meanwhile, Kreitz [38] cites Webster's New Millennium Dictionary of English in which good practices are defined as those that are more appropriate under certain circumstances; or as techniques or methodologies that through experience and research have allowed achieving desired or optimal results. However, points out that often literature is based on studies of cases or brief anecdotal stories to support the statements of the authors, and that the body of empirical research is very small to determine if specific practices can produce these results.

Other definitions relate them to operational procedures and highly effective or innovative philosophies that produce exceptional performance when implemented [19, 90], or any procedure that, when correctly applied, produces better results constantly [17, 91, 92]. Of course, this definition is especially problematic because sentences as *any procedure, correctly applied,* and *better results* are themselves open to debate and interpretation but shed some light on what differentiates a good practice from a best practice.

A small several definitions use the term *best.* For example, for Leandri [86] good practices are simply the best way to perform a determinate function or process, which leads to the results desired by the organization, that others try to emulate, and thus are usually measurable. It also runs through borders, which means that good practices can be used in any context with similar results. On the contrary, for Wheeler et al. [74], Hurts [93], and Halvorson [77] the term is something that has been determined to work well, and within some circles is known as *traditions.* For Davis [94], is the best way to carry out a function or process. Good practices are produced once internal needs have been evaluated and current practices have been identified, and after identifying alternative ways of doing things and modeling best practices about the alternative methods [79]. The comparison of typical operations of the competition is the key to seeing what can be used in the operation [35].

Morin [95] suggests that good practices outline a process, a practice, or a method that can improve efficiency and efficacy. According to this author, a good practice becomes evident when is applied to a specific task instead of being applied to bigger or more general fields. In the document, he uses good practices as a synonym for *tips* or *good ideas*; this is confirmed by Postar [80] and Pérez et al. [15], who opine that the term implies success; that certain actions, attitudes, and programs are the most efficient and effective ways of doing business; and that the same measures can be used with successful results in similar organizations. For these authors, *more efficiency and effectiveness* can be derived from seeing, from the first view, certain ideas or principles that, when applied, produce successful results.

As indicated by these contributions, authors are very far from a shared and widely accepted definition. Besides, it added the difficulty that their works are based on literature as evidence of the existence of good practices when considering the consulted articles as correct and authorized because they have been published. Practically there is no discussion and becomes disseminated because the works must be considered authorized or reliable. Some authors address the definition of *benchmarking,* as Melo et al. [96], and use it as a process of measuring processes and the efficiency of their services, that later are systematically compared to the performance of the other to search for good practices. As commented above, according to this point of view good practices emerge from measuring own services and subsequent comparison with the other. Other authors define good practices as something involving quality frames, comparative evaluation, and performance measurement of products, processes, and services [71, 72].

Finally, many authors do not define specifically good practices, instead, they use synonyms as *commonly used practices* [97], *common practices that seem to promote success in their use* [43], or *practices that are repeated because they work* [83]. For them, literature reviews and standards made by academic organisms seem to offer enough evidence to accept current good practices. Others suggest that good practices can be identified through *brainstorming* sessions [46]; through processes or practices introduced recently that seem to be working well or that have obtained approval from the users [57, 98]; or through traditional practices that have been used successfully through the years [11, 49].

4. DISCUSSION

The results corroborate the studies of Kauppinen et al. [21], Reavy et al. [3], Johnston [22], and the study by Hallencreutz and Turner [4], who concluded that literature is not discovered consistent evidence to clearly define the term good practices, and that is not found a widely accepted definition. The same as the presented results, they declare that most of the definitions are based on opinion and anecdotal evidence.

The previously exposed theory that good practices in literature are based less on empirical data and more on opinions, individual experiences, and anecdotal information is also confirmed in this study. A high percentage of the works of this sample simply do not define the term, and those do that are not in agreement. As a result, *good practices* are used as a synonym for standards, guidelines, good ideas, and common practices, practices derived through comparative evaluation, traditions, and recommended practices. This highlights the variations in the attempts to find a definition and emphasizes the difficulties of building a body of knowledge around good practices because traditions and good ideas are the most efficient and effective ways of understanding them. Some authors try to adopt a more rigorous methodology for describing a process or service, establishing goals, identifying at least two methods to achieve the goals performing pre and post-evaluation when using these methods, or designing identification methods that fulfill goals as a reference point. In theory, this type of study should have higher probabilities to provide reliable evidence about the meaning of this term.

Also, is important to implant a proper formation of good practices, which should begin long before graduates begin to work. This is necessary because if they do not have a clear idea about the meaning of the term and the advantages of learning about this subject, they should copy or get experience on their own until understand what is considered a good practice. We must pay more attention to this issue. Similarly, a proper education requires a more rigorous use of the vocabulary proper for each profession, therefore in each discipline, one must understand the difference between, for example, a good idea, a good result, and a good practice.

What is the meaning of the fact that graduates do not have this type of education or that they may be receiving it incompletely? It is clear that good ideas must be shared in literature and that they must be easily adopted and adapted to transfer them to organizations. At the same time, literature must be read carefully and you must ask yourself questions like those posed in this research. It is needed a critical view of all that is said to be a good practice before trying to apply it or adapting it to the internal processes. When an author writes about this subject should ask himself if the process or practice is a *good practice* supported by successful results, or if this is simply about a good idea, that is to say, something that is done always in the same way because it works. We must be careful to verify and validate before publishing unless we have evidence enough to use this term.

Future research in this field could include a similar study of good practice guides developed by professional associations. However, at the same time is important to pose certain questions before initiating the construction of such guidelines: Does it define good practices? If it is so, how good practices are defined? Are there similarities and differences in the method used for developing these guidelines? What is the difference between the rigor observed in the development of these guidelines for other disciplines? Another alternative is to search studies that have followed these patterns to determine if when applied they improved the efficiency and the effect. As pointed out by Reavy et al. [3] in their study, increasing research and comparing the efforts in the different disciplines and their results could help to build a body of transferable knowledge to other organizations and situations. It is noteworthy that many of the services and processes described in the analyzed documents are initiatives implemented in only one company.

As a final consideration is important to consider that expected to have professionals more and more responsible and expected they quantify and document the effect of the services. Therefore, organizations of any type, today more than ever, must participate in a more rigorous evaluation of services and programs used, methodologies, and techniques of evaluation implemented. This universe of results would serve to build a bigger body of literature, based on solid evidence, and have reliable documents that allow determining good practices in any process or service.

4.1 Good/best practices in new and complex cultural contexts

Because in the conducted literature review a clear definition of the terms practice and good practice was not found, next is proposed a definition that has been built by the authors based on their experience with new and complex cultural contexts. It is not an opinion, but the result of validating it in different processes and disciplines, and other researchers have verified that works in their expertise field.

4.1.1 Practices

It is a method, procedure, process, or rule widely used in a discipline or profession. A set of practices is considered a standard. In the English language, we must observe the terms *practice* and *practice,* and although they seem to be similar their meanings are different: *practice* is a noun that refers to the action itself, it is not referred to the person performing it; meanwhile *practise* is a verb that means performing something repeatedly to improve skills, a systematic training through multiple repetitions to improve or dominate skills. In other words, it is important to note that *practise* is a verb and that *practice* is a noun.

4.1.2 Good practices

It is a technique or methodology that, through experience and research, has demonstrated that reliably leads to expected results, and that, as a knowledge body, can be adapted to any discipline. However, the commitment to the use of good practices in any field lies in using all the available knowledge and technology to ensure success. Good practices tend to become widespread in a field or industry after being demonstrated its efficiency. However, although they are well supported we can see that this is a slow process, even inside the organization. According to the America Productivity and Quality Center, the three main obstacles to adopting a good practice are

1) the lack of knowledge about current practices, 2) the lack of motivation to perform the changes involved in their adoption, and 3) the lack of knowledge and necessary skills to do that. A good practice is less than a standard and more than a pattern of thinking associated with its design. The standard is the exit door while good practice is the entrance of associated thinking. Thinking can be replicated to create wider organizational capabilities; however, solutions change as the environment changes.

In this respect, the terms *best practices* and *good practices* are found repeatedly in literature but their meaning seems to be assumed only to being popular, therefore they can blend. To define them is necessary to discompose their words:

- *Best.* Surpass everything else in excellence, achievements, or quality; the most satisfactory, appropriate, or useful; the most highly qualified.
- *Good.* Being positive or desirable; having desirables or distinctive qualities in one thing; serving the purpose or desired goal; greater than average ones.
- *Practice.* To perform usually or by the force of habit; doing or carrying on (something) several times to acquire or improve abilities; offering reiterated lessons or instructions for something.

Consequently, a best practice suggests that there is a technique, method, process, activity, incentive, or reward that is more efficient than any other to deliver a result. This concept indicates that by having appropriate processes, controls, and tests we achieve results with fewer problems, complications, and unexpected events. Good practice also can be defined as the most efficient and effective (requiring less effort) way to perform a task (better results), based on repeatable procedures that have proved to function. A good practices strategy is where the organization makes efforts to replicate what is considered appropriate for an activity. To achieve that, it must use a series of tools to perform proper management, like networking, comparative external evaluations, quality searching, strategic planning, and performance management, among others. This implies finding and using better ways to work to achieve organizational objectives, but it must try to be updated about the operating way of successful organizations and be updated in the measurement of their ways of working compared to those used by the leaders of their environment.

The *best practices* are neither an untested theory nor an opinion but are that which are obtained when *good practice* is applied to achieve the highest standards. Both terms have been under terminology degradation. Many people propose that would be better to return to obvious common-sense interpretations, but in this postmodernist world, this is unlikely.

5. CONCLUSIONS

Increasingly more organizations are forced not only to demonstrate the profitability of their investments but also must provide reliable statistics and other data based on evidence. As such, they must improve their comprehension of what is meant when they use terms such as good practices, besides, is essential that researchers increase the rigor of their analysis before publishing results.

At the same time, is necessary to recognize the risk of supposing that there exists a universal criterion for the practice of every discipline. Adopting methods and processes anybody recommends as a good practice could result in a substantial loss in organizations. Besides, given the complexity of current environments, a good practice could dampen a critical problem and truncate creativity, thus, ironically, inferior results would be achieved. A context like this could reduce the process to simply adopting a practice whose results are not replicable in the unique environments of each company. However, this does not mean that the search for good practices must be abandoned completely, but that is necessary to perform careful approaches before concluding that practice is *good,* and avoid going into a kind of illusion.

In the literature, the term *good practices* is used widely, but in very few words we can find a definition. Besides, almost every work presents meanings sufficiently vague to say nothing. When an organization wants to use good practices generally this means meeting established standards by similar organizations. These practices are very normal, but not the *best*. This results in that generally the term is associated with the method or the technique (a procedure, a standard, a team piece, an informatics system) rather than a thinking pattern, and we miss the true intention of the term and its subsequent role because currently, it seems to be set aside as a mere mechanism.

Because of all this, the term has become a fashionable word in the business world, which often is used in some marketing strategies to achieve a sale transaction, but rarely is the necessary work to consider practice as good; however, most of the time, good or intelligent practices are found that offer ideas about solutions which can function or not in each situation. Although the recommended practice can vary in function of the context in which it is applied.

Other people seem to disagree with the term good practices in general since it limits the capability of for searching a better way of doing things. The word *good* tends to symbolize that there is nothing better, therefore it is promoted as the only way to do it. The *good practices* today must be only a baseline for *best practices* tomorrow. Besides, the perception of the original intention of the term, of being the more efficient and effective method for achieving results, has become extremely vague and now is a fashionable word used to describe a field in which something is done to promote a perception of excellence.

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IV
A structured model for knowledge management in engineering

In this chapter, it is proposed a method to manage knowledge in engineering through a series of activities and processes that allow the organization to find the wisdom it needs to preserve and update its knowledge encyclopedia. An analysis of the need to manage knowledge in engineering is presented, but differently from how it is done in other areas of the organization. A method is proposed to achieve this objective, in the sense of taking better advantage of what engineers know and learn in the development of their activities and initiatives. Although it is traditionally assumed that knowledge management models work for the organization as a whole, the reality is that in light of current developments, this conception must be reformulated. It is not the same to manage knowledge in engineering, where its creation, updating, and retirement are dynamic and accelerated, then in other corporate areas where it is created and updated very slowly. Moreover, a different way of managing it is needed, because in engineering the sources of knowledge are multidimensional and its relationships with other areas are transdisciplinary.

1. INTRODUCTION

To stay competitive in globalization, companies are looking for new ways to obtain and protect their most valuable asset: knowledge, which many consider their intellectual capital. In this era, it is common for them to have access to the same processes, techniques, and methods for managing data and information, and the only thing that differentiates them is the knowledge they discover, apply, validate, and document within themselves. According to Kock et al. [1], in a typical organization, approximately 68% of the processes that support its business model involve the exchange of data, information, or knowledge. But nowadays and with the progress of technological developments, this percentage has increased substantially, because dependence is also increasing as an imposition of globalization.

As part of this trend, knowledge management in engineering becomes a necessity in corporations, which begin to implement systems to achieve that the tasks related to information and knowledge in this area support their business model. But when they try to manage this type of knowledge traditionally, problems arise, because the general rules for creating, discovering, and documenting the information and knowledge generated in engineering are of little use [2]. In part, because they are dynamic and highly complex, i.e., they do not follow traditional patterns of knowledge management, as it is managed in other areas. Knowledge in engineering presents definitions of attributes and classes, relationships between components and parts, geometric and spatial specifications, specific configurations, mathematical expressions, and application definitions, which are not common in other areas. In addition, engineers have specific ways of validating and communicating learned or experienced practices, so a special translation process is necessary to document them as part of the organization's assets [3].

Another aspect that hinders this management process in engineering is related to the language used [4]. While in other areas management is developed from and based on natural language, in engineering this language generates ambiguities that make management an arduous and complicated task. That is why engineers prefer to use mathematical symbols because they facilitate the documentation, interpretation, and application of validated knowledge [5]. In this sense, management must contemplate these characteristics and provide the necessary tools and support, so that this knowledge can be stored in the corporate *knowledge encyclopedia*, and so that its consultation and application do not leave room for interpretation errors.

An additional benefit to this type of knowledge exchange results from the elaboration of a neutral language of representation because this is how engineers have been trained as professionals and have developed their skills and abilities. On the other hand, this format can represent a greater amount of knowledge, because its structure is mathematical and unmistakable. Also, management improves in terms of application and dissemination, because it offers a framework in which knowledge, as an active agent, can be moved from one system to another, while being stored in the central knowledge encyclopedia as a special repository, together with other organizational knowledge. This framework is mainly used to support processes in which engineering knowledge is the engine of development and innovation for the company.

This chapter analyzes knowledge management in engineering as a process of creating/discovering, understanding, comprehending, sharing, applying, experimenting, validating, documenting, updating, innovating, and storing, but always oriented to continuous improvement because in engineering knowledge is considered dynamic and complex. In this sense, a structured model is proposed to achieve this objective, while describing a framework of processes and challenges that arise when trying to implement it based on traditional knowledge management.

2. ENGINEERING KNOWLEDGE

Knowledge management means structuring, implementing, and managing a series of strategies and practices to identify, create, represent, distribute, facilitate, and transform information and experiences into useful knowledge for a business model. These strategies and practices are developed individually or in groups and can originate from inside or outside the company.

To classify the types of knowledge in the engineering context, different frameworks have been proposed [6]. A widely spread and accepted one defines them based on the dimensions of *tacit* and *explicit* knowledge [7], where the former is the one that each engineer internalizes individually, although he/she may not be aware of having it, while the latter is completely conscious and can communicate it easily [8]. Likewise, for Hayes and Walsham [9] the *content* and *relational perspectives* of knowledge and its management in engineering are different epistemological perspectives. On the one hand, the content suggests that information and knowledge can be easily stored because they can be codified; while the relational perspective recognizes that they are difficult to share outside the scope and relationships in which they are produced. That creates an additional difficulty in knowledge management in engineering because the contexts in which it is created or identified are complex and multidimensional, and its relationships are transdisciplinary [10].

Because of these particularities, engineers are called upon to convert tacit knowledge into explicit knowledge, while documenting and sharing it. This effort aims to internalize and give personal and organizational meaning to any knowledge they create or discover in the business model [6, 11]. However, some researchers argue that distinguishing between tacit and explicit knowledge is a simple representation of reality because the notion of the latter is itself contradictory [12]. They argue that to make engineering knowledge explicit, data must first be translated into information, i.e., represented by symbols outside the mind [13, 14].

In this sense, Nonaka and Takeuchi [15] propose a model for socializing, externalizing, combining, and internalizing knowledge, which can be adapted to the characteristics of what happens in engineering. These authors consider that the objective can be achieved by intervening with an interaction of knowledge processes in a spiral between both knowledge, through a cycle in which the implicit is extracted to become explicit. Although this proposal attracted attention and was considered by some companies, many abandoned it because the cycle itself is difficult to keep active.

Subsequently, attempts were made to return to this scenario to reopen the debate and research on this conversion process [16], but in the last decade knowledge management in engineering has become more complex and it has not been possible to apply the adjustments proposed by the model. Closer to a form of knowledge management in engineering could be considered the proposal of Serna and Serna [17], Serna [18], and Serna and Serna [10], because it is framed in this area of knowledge because it could be considered as the first to address this challenge, involving transdisciplinarity and the multidimensionality of the knowledge to be managed.

As to how to categorize the dimensions of knowledge, some approaches affirm that, on the one hand, it is embedded in systems external to people (as in Information Systems) and, on the other hand, incorporated into them and represented in the capabilities learned through their systems (such as the sensory) [19]. According to this author, knowledge is built from the data and information processed by each individual, as well as from the one previously stored. His thesis is based on the fact that the implementation of efficient engineering knowledge management depends on the leadership, culture, practices, and IT infrastructure in organizations, and on the skills possessed by the engineers who promote it [20]. This becomes difficult when the work teams in charge of this management do not internalize the knowledge of what they know and experience. Therefore, it must first be made visible and then understood and managed, because otherwise, it would only be data and information at a personal level.

The third framework of knowledge dimensions recognizes that the creation of new knowledge is achieved through exploration, i.e., innovation and that the knowledge achieved is transferred or exploited among individuals, groups, organizations, or communities [9, 21]. Because engineers work in collaborative environments, such as communities of practice, or use computer tools, these dimensions could be involved in the management of the knowledge they create or discover. This approach is directly related to the postulate that knowledge is dynamic and that it can be transformed, transported, and shared because it is humans who create and/or discover it [22].

Another important issue is that engineering activities and processes have short application and use times, so knowledge is continuously accessed: before, during, and after management activities [23]. That is why engineering organizations must design structures to capture it, including a process that few models take into account: the transformation of data into information and information into knowledge. If engineering does not proceed in this way, the teams may manage knowledge, but they will not generate the *wisdom* that should compose a management process in the area and that the organization will include in its knowledge encyclopedia [24].

In this sense, it must be taken into account that a knowledge management strategy in engineering implies a permanent reinvention of ideas, creations, and practices. Moreover, it must be recognized that engineers strive to codify what they know, but rarely share their knowledge repositories, or such codification is personal and cannot be interpreted by others. That is why, almost always, their databases are difficult to retrieve and *new knowledge* is required to interpret and apply what is documented in them [8].

On the other hand, in engineering, it is common to seek knowledge from consultants with extensive experience, who contribute their views on a particular subject and provide knowledge to inexperienced engineers to expand their own or modify the management they carry out [7]. This strategy is developed in a simple framework in which knowledge and information are codified and customized, and consists of collecting and storing codified knowledge from consultants, databases, and the engineer executing the process [9], i.e., it can refer to both tacit and explicit knowledge [25]. The objective of this type of customization is to motivate engineers to decode knowledge and share it with the group so that the organization can increase the *encyclopedia of* organizational *knowledge*.

In general, in the context of engineering, specific initiatives could be structured and implemented to achieve this and other objectives related to better knowledge management. Some of them are described below:

- *Decision making*. By tracing the documentation of decisions in terms of a sequence of events and the rationale for each decision, an audit trail is provided for the future use of each decision, even when the engineer in charge is not present. This traceability functions as a historical route memory of the positive and negative experiences, which have been gained when making decisions based on the knowledge acquired or created, and stored in the knowledge encyclopedia.

- *Development and distribution*. The idea is to evaluate the results of the decisions made, to form a useful knowledge base for later decisions. To achieve this, engineers must form and work in collaborative teams in which they define the orientation, good practices, and evaluation of the results obtained. This would be like fostering a culture of learning from experience so that the next generations take advantage of this embedded and collective advice from the engineers before them.

- *Specialization*. It focuses on the access and exchange of information and knowledge in specific engineering domains, traditionally provided by organizations through their engineering standards or technical references. This increases the level of demand because these standards and references undergo frequent revolutions and, if engineers do not have access to them or are unaware of them, the business model may suffer setbacks or incur legal faults. This specialization requires that information and knowledge be shared through interaction among engineers, regardless of whether they are internal or external to the organization.

Based on this, and to better manage engineering knowledge, it is necessary to take into account the following:

1. If management's focus is on *decision-making*, the company must identify and deploy the necessary and sufficient technology for engineers to identify and document the results of decisions made. In addition, deploy structured procedures describing the steps, objectives, and products expected from such decision-making, to ensure proper management and recording in the organization's encyclopedia of engineering knowledge.

2. If the focus is on *development and distribution*, then engineers, with the necessary support and sponsorship, must design, promote, and apply forms of collaborative work. In this case, the most important thing is the consensus in the group, because it guarantees the acceptance and application of the knowledge to be managed. One way of doing this could be through formalized structures for recording practices and experiences, successful or not so that management can be based on them.

3. If management's attention is focused on *specialization*, the organization must clearly define the means to access knowledge. This involves principles and laws that could lead to non-compliance with the quality and distribution criteria of the engineering product, which would be counterproductive for the company. On the other hand, it is also necessary to adopt the best practices, new or experienced, to reference and document the learned process. This is a basic principle of efficient management.

3. MODEL FOR MANAGING KNOWLEDGE IN ENGINEERING

Knowledge management is a function that must be performed as a work behavior in organizations because when properly executed it becomes a bridge between practice, experience, and task automation. Moreover, because engineering is transdisciplinary, interactive, complex, and multidimensional, knowledge management must be a dynamic, generative, high-level, and on-demand process. On the other hand, engineering is the area that continuously pushes the industry in search of progress, development, and innovation, so it is necessary to identify the critical factors that motivate engineers to constantly seek new knowledge and, then, implement an assertive updating and management of the company's knowledge encyclopedia. This will result in continuous improvement and approaching the quality of products expected by society and required by the standards.

Another factor that cannot be overlooked in engineering knowledge management is the development of IT. This industry has progressed enormously since the 1980s and improvements in information storage, along with computing power, are features that engineering must take advantage of. One of the problems that organizations encounter is that this area is also engineering, so the recommendation is to structure IT with sufficient capacity to meet the demands of the business model but also to respond to the demands of knowledge management in the knowledge encyclopedia [26].

However, because software maturity levels are not yet those required to meet the needs of society, engineering must develop its tools to discover, create, document, assimilate, disseminate, appropriate, use, and store the knowledge to be managed. In addition, and as an activity proper and almost exclusive to engineering, a process must be developed to translate human knowledge from a natural language to a formal one. The product is stored in the knowledge encyclopedia because it is an essential requirement to take advantage of the power of computation in the management of what the organization knows and knows in engineering.

On the other hand, as engineering knowledge is transdisciplinary and multidimensional, it generates a higher level of complexity in its management. In this sense, automation has been proposed as an alternative, but many organizations have failed in this initiative [27, 28]. This is due to the inherent dynamism of engineering, which makes it impossible to establish unique rules of behavior and the origin of this knowledge. The numerous systems that are related and interact in the creation and generation of knowledge in this area make it improbable to predict its behavior, quantity, and potential, and to define the best way to manage it and take advantage of it using a static tool.

In areas other than engineering, automation processes have experimented with variable results, but it is common to find comments on the difficulties in terms of integration, flexibility, and adaptability in each organizational environment [29]. Artificial Intelligence and neural networks do not yet offer mature human-machine interaction tools for automated decision-making, and not all those promoted as such turn out to be good applications for knowledge management. These difficulties stem from the fact that the characteristics of knowledge in engineering are unique compared to areas such as economics and management [30, 31].

A model to manage knowledge from the engineering point of view consists of a set of instructions and guidelines on how to perform a complex procedure. This is necessary, because, to achieve the objective, the tasks must be detailed, as well as the form and order on how they will be carried out, in addition to the documentation procedure, although many attempts to manage knowledge in engineering are carried out without a specific method [32]. Because this area is very active and not having established procedures generates chaos in how to manage the volume of data and information that is generated in each procedure, the use of a method is vital to respond to quality, for reuse and to properly maintain the knowledge encyclopedia in the organization. Moreover, as systems change and new solutions are experimented with and validated, it is not possible to manage the evolution of the knowledge involved and to generate new knowledge from existing knowledge, without formal procedures. In this sense, a model for knowledge management in engineering should contain:

1. *Details of the activities* to create, discover, share, and document the data, information, and knowledge generated in the engineering processes. A basic function when the objective is to acquire knowledge for the sustainability of the business model and the knowledge encyclopedia.

2. *Instructions* describing the step-by-step instructions for engineers to include what they know in the knowledge encyclopedia.

3. *Validated techniques to develop the tasks*, because the good practices learned should generate enough experience on how to obtain the best results in terms of knowledge management.

4. *Documentation methods and formats*, in which the history, experiences, and results (positive and negative), individual or group, that are achieved by using the knowledge stored in the knowledge encyclopedia are captured. This documentation is used to update, discard, or innovate what has been recorded up to that moment.

5. *General recommendations and guidelines*, in the sense of indicating to the managers how the drawbacks have been overcome and what wisdom has been achieved in the process.

The advantages of such a model can be summarized as follows: novice engineers benefit from what experienced engineers document; product generation processes respect what has been validated and do not omit essential issues; procedures are standardized in terms of knowledge creation, documentation, assimilation, and management; engineers can document directly from the knowledge encyclopedia, without the need for personalized tutorials; knowledge and good practices are reused; the knowledge encyclopedia is permanently updated and queries are made on validated knowledge.

Likewise, the outstanding problems in its application lie in the fact that most approaches to managing knowledge do not take into account its dynamic nature. Moreover, *knowledge is a constant flow of believing, knowing, applying, and transferring* [18], and if it stops in any of these actions it loses the sense of surprise and its usefulness would be limited to trying to predict, instead of applying. On the other hand, engineering processes go through an alternating flow of changes and innovations, and engineers are needed to apply, update, and project them to take advantage of them in a very short time. Another difficulty arises because traditional management models do not communicate effectively with all areas, something that is complicated in engineering. After all, knowledge has multi-dimensional sources and its relationships with other areas are transdisciplinary.

This creates problems between traditional management and a method to manage knowledge in engineering, because management is not dynamic, because when the organization approaches a process of change the rules cannot be configured efficiently, and any attempt to innovate does not go beyond being a new version, although with the same rules and bases. In other words, whenever new knowledge is discovered or when it must be replaced, actions are not automatically executed, which generates reprocesses or delays in the responses that an organization must generate to be competitive. Table 1 details the model for managing knowledge in engineering.

Table 1. Model for managing knowledge in engineering

Activity	Process	Challenges
Create/Discover	The engineer finds data and information and structures new ways to perform his functions with better results.	The training of engineers does not allow them to develop logical abilities to apply new ways of thinking about a function.
Understand	The engineer can apply the new knowledge in other scenarios.	The micro-specialization of engineering does not allow the engineer to perform in different scenarios.
Understand	The engineer models, documents, and internally assimilates structured knowledge	Engineers need to develop logical reasoning and systems thinking to understand what is going on in their minds.
Apply	The engineering decodes and structures knowledge application processes.	The IT is not structured to assimilate this type of process.

Share	The engineer codifies and communicates the understood knowledge to the work team.	The work is done as a group, not as a team, so it is difficult to make others understand what is created on a personal-individual basis.
Experience	The organization experiences the knowledge to develop and advance the business model.	Business models have almost the sole function of responding to projected profits for a given period and are not forward-looking.
Validate	The organization validates the results of the application of knowledge through acquired development.	Verification is a process that encounters administrative barriers
Document	Engineers document the processes and experiences within the work team.	Work teams do not have a formal coding language.
Update	Work teams update the encyclopedia of organizational engineering knowledge	Information and knowledge in the organization are stored in traditional repositories and without a unified structure.
Innovate	Based on the updated knowledge, the organization establishes lines of attention to the business model and projects new uses and utilities	Foresight in engineering is practically non-existent and future decisions are made based on data projection, not on acquired wisdom.

4. CONCLUSIONS

An analysis of the need to manage knowledge in engineering is presented, but differently than in other areas of the organization. A method is proposed to achieve this objective, in the sense of taking better advantage of what engineers know and learn in the development of their activities and initiatives. This could improve productivity in organizations and make their business model have alternatives to keep them productive in globalization.

After years of existence, the conceptual bases of knowledge management are still difficult to define, especially as a comprehensive set of technologies for companies. This is what must be taken advantage of in today's organizations because technological development advances at a pace that these bases can neither support nor maintain, so it is required that the same knowledge that generates the developments, that is, engineering, has to be managed differently and with a strong perspective vision. This chapter proposes a method to achieve this and analyzes the challenges that engineers must face if they decide to apply it.

One of the key challenges of the research and application of this proposal is the need to take advantage of the capacity of engineers to generate data, information, and knowledge because traditionally it is expected that knowledge is delivered ready for consumption; but in engineering, this is not the case, because its professionals generate data that must be converted into information and then into knowledge, and the process must continue, that is, that knowledge must evolve into wisdom because only then can the organization claim to have sufficient input to incorporate it into the knowledge encyclopedia. To carry out this process, it is necessary to modify how what engineers create and discover is used, in the sense of designing a formal language to interpret, transmit, and document the diverse solutions they find and experiment with. This allows the permanent supply of knowledge and its reuse by consulting the knowledge encyclopedia, enriching the semantics of the management model, and guaranteeing the traceability of solutions in the engineering processes, while providing a framework for evaluating opportunities to project the business model.

This is promising, in the sense that it is a technology that allows organizations to personalize individuals' own experiences through the possibility of distributed deployment of tools; although sourcing, reuse, and traceability are important aspects of efficient engineering knowledge management. This enhances the company's potential to respond quickly to market needs and to generate innovative alternatives that meet the specific requirements of its business model in a global world.

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V
Model to diagnose the level of technological maturity of the companies[1]

Following the new economic context generated by the Covid-19 pandemic, this chapter proposes a model organized in three stages: 1) reinvent, 2) find the level of maturity, and 3) diagnose, to determine the level of technological maturity of companies, which will allow them to approach a structuring of their systems before deciding to implement new technologies, without which they may not achieve adequate economic recovery. In the integration, they will be able to better connect the internal processes of technological management, improving at the same time the communication and business processes with external partners. The recommendation is that these stages be structured as strategic processes, in the form of an action plan and with a vision shared by all stakeholders.

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1. INTRODUCTION

It is a no-brainer to accept that new technologies are the most important issue for business in the New World Order. While history has seen major moments that have affected business development, such as recessions and the resulting social and economic crises, it is not necessary to digress too far to identify the Covid-19 pandemic as a moment that has impacted individuals, states, and organizations alike, and its mark is far from over. Moreover, globalization and offshoring are key forces generating a reconfiguration of corporate strategy and structure to face these moments, and those to come. On the other hand, the effects of the pandemic on global demographics are also causing profound and lasting changes in markets, production, and the supply of services.

In any of these scenarios, new technologies play a leading role, and the reason is that, in the wake of Covid-19, the development of digital is removing restrictions and creating new and exciting possibilities that are affecting and will affect the performance of companies around the world. Social media has finally made customers heard, forcing companies to move away from the narrow lenses of surveys and focus groups. Mobile computing proved that it is possible to have ubiquitously available and productive employees. Data science leads to significantly better forecasts, judgments, and decisions. In addition, new technologies offer companies the ability to implement revolutionary organizational structures, business processes, and customer offerings that are completely innovative and can be rapidly modified as the New Era progresses through the century.

These and many other technological advances amaze everyone, but the most important impact is seen in the way they change the way people live and work, making it easier to perform processes and activities that seemed impossible a decade ago. The last time there was this much technological innovation in the business world was during the Industrial Revolution when machines bent the curve of commerce, capitalism, and, indeed, human history [1]. Likewise, in this century new digital technologies are leading humanity into what McAfee and Brynjolfsson [2] call the second machine age.

In the wake of this reality, entrepreneurs have to question whether they and their companies are ready for this second era, but when analyzing the results of many types of research the answer may be that they are not yet; because the findings show that, in most countries, few companies are using new technologies to drive significantly higher levels of profitability and to improve productivity, performance, and quality. Therefore, most companies are not achieving digital mastery, which is not encouraging since such achievement is necessary to survive and thrive in the New World Order.

However, there is also good news, since the reasons why these companies do not achieve digital mastery are not many and it is not difficult to overcome them. Hence the importance of conducting a proper diagnosis to determine their level of maturity about the decision to implement and take advantage of new technologies. If before such diagnosis they venture to initiate digital transformation processes, they may become one of the many who struggle to become truly digital but fail to develop real capabilities to work differently, establish their vision, and execute it. Although the media reports cases of technological appropriation in large companies around the world, it must be understood that not all of them take advantage of new technologies because many have been launched by the New Era to implement this process and, although they continue to operate, it cannot yet be said that they have achieved digital mastery.

In the business world, it is common to talk and debate about the Fortune 500, and in much-specialized media they devote ample space to analyzing what this list of companies with the highest revenues implies for the economy as a whole, discovering trends, and trying to reach conclusions about them. For example, they found that 61 companies on the 1955 list were still on the 2015 list. This meant that the business structure of fifty years ago was sufficient for companies to remain current and productive for more than sixty years. However, the New World Order showed them that life expectancy was drastically reduced to just a decade [3]. So, the learning is that past performance is not an indicator of future performance, so entrepreneurs cannot blindly rely on their business strategies today, no matter how successful they are, because they may not be adequate to stay competitive in a New Era where digital is blanketing the planet.

Now, in this context, companies should be concerned first with whether they are going digital, not whether they have already implemented digital changes. They must ascertain, although they probably have, how they are influenced and affected by new technologies or how they will soon be. In other words, a company starts to become digital when:

- Your management and the way you make key decisions are affected by big data or analytics and artificial intelligence.
- Your customers' actions, interactions, and consumer preferences are driven by the social web.
- The way it offers its services to customers is oriented from mobile applications and cloud computing.
- The Internet of Things links your products through sensors and software to wider machine networks and the cloud.
- The evolution of its supply chain is driven by robotics, drones, and 3D printing.
- Cognitive computing algorithms and robotics influence how they reinvent themselves and adapt to each moment.

It may be that at least one of these characteristics applies to every company, or will soon do so, but if not, it is likely to apply to customers and competitors. As the century progresses most companies will find that new technologies begin to impact, in some way and directly or indirectly, their business model. Let's go a bit to the extreme and suppose the company says no to all of the above characteristics, then it will have to worry because it is likely that for its competitors the answer is yes. Because they see things differently and achieve better competitive advantages, which are better to have than to envy.

Deciding to change is not easy, but in the New World Order, it is inevitable and necessary for companies to grow, survive, and be competitive in the post-pandemic era. Regardless of whether you are a Fortune 500 company or not, the important thing is to have confidence in continued success and to develop mindsets and skills to integrate and leverage new technologies [4]. No matter how many of the above characteristics the company answered yes to, what it needs is to systematically understand the process and its rules, evaluate options, and make rigorous short-, medium-, and long-term decisions. But before starting it must perform a diagnosis to determine its level of maturity about the decision to implement and take advantage of new technologies, on this depends the success of the company during and after this crucial period.

Next, the stages that make up the proposed model are described: Reinventing the company, determining the level of maturity, and diagnosing the process. Subsequently, the conclusions and references used in the construction of the text are presented.

2. REINVENTING THE COMPANY

The impact of disruption and transformation on traditional businesses is an issue that receives widespread media attention, and the reason seems justified, because new technologies profoundly impact the world in this century, revolutionizing everything from social interactions to corporate structures and the way business is conducted, allowing some companies with a vision of change to achieve exponential growth. But not everything is linear, because, at the same time, new and agile players are emerging with innovative and adapted business models that break this linearity. Consequently, while new technologies may represent a threat to the traditional company, they also offer enormous opportunities to adapt to the opportunities of the New World Order.

On the other hand, in this century in the business world, the term digital has become synonymous with disruption and transformation, and many companies have probably initiated processes and experimented to go digital. Some may have succeeded, but many have not. So, if the goal of every entrepreneur is to emulate the success of those who succeeded, they will have to seek a more transformative impact for their business, which necessarily leads them to have to develop skills to make the most of the unique opportunities offered by the New Era [5], while reinventing the management and administration of the company. In the process, it is necessary to distinguish what works well and what does not in the business model and to accept that new technologies provide substantial support to improve it. In other words, it is necessary to treat the digital strategy as inseparable from the overall strategy of the company, lead the change with a priority mindset, and ensure that this strategy encompasses all organizational processes, starting with the human factor [6] because the transformation must begin by strengthening the foundation and building for the future at the same time.

But you don't need to create a lot of fog and mystery to reinvent your company, you just need to learn from those who have succeeded and not repeat the mistakes of those who have failed, while defining what can work for your business model, people, and customers, because every company has its DNA. The following framework for business reinvention will help you leverage what works and identify areas where new capabilities need to be developed. The framework consists of four key dimensions, as shown in Figure 1.

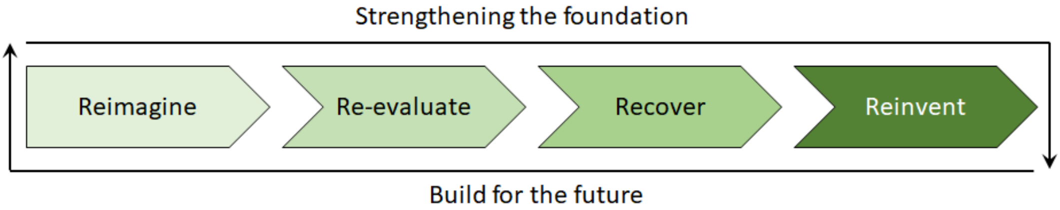

Figure 1. Framework for business reinvention

2.1 Reimagining the company

As a result of the progressive and numerous changes that new technologies have generated this century in the business world, entrepreneurs are obliged to reflect and analyze the essence of their companies, for which they must examine the scope, the business model, and the ecosystem they inhabit. In analyzing the business scope, one must be sure what the business is and what should be invested in. Competition in the New Era generally emerges laterally, from new players, so it is important to innovate the scope of the business to keep it competitive. But focus on core competencies, because experimentation can be destructive to new aspirations [7].

As for the business model, the analysis should focus on how the company creates and captures value because as models change and direct and indirect competition begins to affect the business, it is possible that the current model will not be able to succeed and remain in force. These indicators should be seriously analyzed and the company may feel the need to stop fighting alone and join an ecosystem made up of both partners and competitors. This will help it to create commercial platforms and redefine the image of the competition. But we must be aware that changing a business model, driven by the sale of products, to the creation of an ecosystem, forces the entrepreneur to radically modify his business mentality and create different and innovative strategies to maintain and project the company.

2.2 Re-evaluate the company

Well-analyzed, implemented, and structured, new technologies can substantially improve the efficiency and effectiveness of business processes and, in this century, have given way to the emergence of the so-called Industry 4.0 era, in which technologies such as digital manufacturing, virtual, and augmented reality, 3D printing, and supply chains are being innovated, resulting in the achievement of the desired operational excellence. In re-evaluating the enterprise, it is necessary to analyze how new technologies are leveraged to improve productivity, reduce failure rates, and create competitive advantage.

In this New Era, innovative companies are using digital technology to modify the traditional value chain, especially in the distribution process, which means that, in reimagining their business model, they are starting, for example, their trade channels. The challenge here is to learn to manage the conflict that arises between traditional and new channels because it is possible to abandon one that is basic for equally traditional customers, then a synergy must be created between these channels so as not to allow the imbalance.

2.3 Recovering the company

One of the outstanding changes during and in the post-pandemic that new technologies have generated is reflected in the way customers search for information and purchase products, which has at the same time generated new opportunities for companies to collect data on consumer decisions and preferences, which they can use to create market niches or to attract new customers.

While this process seems somewhat automated, even advances in neuromarketing have failed to improve consumer preference rates for online ads. The point is that all brands want to attract them, but the messages used do not present them with convincing reasons to do so. The answer is not only to implement or develop technologies and capture data; what companies need to do is to offer a unique and differentiating value to draw consumers' attention to their products. In this way, the company recovers, customers are convinced and markets are opened.

2.4 Reinventing the company

The Covid-19 pandemic meant that many companies had to reduce administration costs to compensate for the decrease in revenues and now, amid the recovery, businessmen are looking to rebuild them to how they were before, which is not a good idea. The reason is that companies used to be successful by using broad and equal business models for all customers, but the situation today is different because the market has become segmented. This has made entrepreneurs have to analyze and understand each segment in which they can compete, understand customer preferences, and offer the right services to the right customers in the right way. This creates the need to reinvent companies and restructure business models to adapt them to the new post-pandemic reality.

The issue is that managing this transition is not a trivial process, since, on the one hand, the objective is to strengthen the base and, on the other hand, the aim is to build for the future, all at the same time, a situation that places the entrepreneur in front of the challenge of having to manage two businesses in parallel. Therefore, it is not uncommon for profits to decline at the beginning, and, without the fortitude and determination to move forward, it is possible that this situation will not be overcome. Therefore, a key idea for business reinvention is to take advantage of technologies such as big data, artificial intelligence, and machine learning, which can automate processes while helping people develop the skills and capabilities that the company needs today and will need in the New Era [8].

3. DETERMINE THE LEVEL OF MATURITY

As has been made clear in this work and different research and proposals around the world, the efficient and effective use of new technologies offers companies the opportunity to achieve economic recovery in the post-pandemic era. However, many of the processes of integration of these technologies are initiated without an adequate study of the state of the company and its real needs. Some try to implement them in selected business processes, such as production or logistics, forgetting that the company is a system in which all processes are related to materializing the business model.

It was said before that, as a result of the effects of Covid-19 on the economy, entrepreneurs must reinvent their businesses to insert them into the New Era and remain competitive in the economic scenarios that emerged afterward. That is why Reimagining, Reevaluating, Recovering, and Reinventing the company, strengthening the base, and building for the future, become the first objective before making hasty decisions to incorporate technologies without a precise north. After judiciously executing these activities, the next step is to determine the level of maturity of the company regarding the decision to implement and leverage new technologies, and then diagnose that level and make decisions. This requires a complete and extended analysis of all areas of the company, including, for example, production management, logistics, quality management, human resources, social and environmental responsibility, and innovation and projection, among others.

Then, the second activity is to determine the company's level of maturity regarding the decision to implement and take advantage of new technologies, as an activity after its reinvention. The concept of maturity was proposed by Crosby [9], who defined it as a state of completeness, perfection, and readiness, although various maturity models have been structured and presented since then, in general, the objectives of applying them are the same: to diagnose and plan. The former is to determine the maturity factor and the latter is to define the development path and practices needed to increase the maturity level of the factor.

3.1 Proposed maturity model

The maturity model proposed in this work is evolutionary, that is, it is made up of a series of stages in which the level of complexity increases with the idea of achieving perfection. The model is made up of five stages (levels) to evaluate the maturity of the company about its desire to implement and take advantage of new technologies. This level of maturity is described in a progressive scale of results: predisposed, reactive, appreciative, organized, or optimized.

The company is considered to be at the predisposed level when it discovers that it does not have an adequate capacity to select, implement, and take advantage of new technologies, both from the internal and external environment. Some internal areas may be specialized in and take advantage of certain technologies, but they are limited to the local level. In general, the company does not have the necessary and adequate tools to implement and take advantage of new technologies in all processes, because it has a low perception and high lack of knowledge of them. Some people or areas may exhibit adequate handling of technologies, but it is restricted to very local environments. Due to this low perception capacity, the company has difficulties adequately adapting to the demand of learning for human resources. This is reflected in the fact that it cannot develop/innovate mechanisms, complex responses, and adaptations to changes in the economic environment, in addition to not offering new and attractive products. As mentioned above, some individuals or areas within the company may have the ability to carry out these activities, but this does not mean that the company as a whole knows how to do so.

1. The company is at the reactive level when it responds and adapts to external pressure and becomes aware of the need to improve the management and use of new technologies; for example, when it receives signals from a certain market domain, it responds with the acquisition or implementation strategies to meet and adapt to it. In the same way, it has learned to make better use of some of its technologies or to select external ones through analysis. At this level, the company's learning process about new technologies is similar to the experience that people go through in childhood: it begins to tune in to the voices and gestures of its innovative employees but still finds it difficult to recognize the signals coming from the ecosystem in which it carries out its activities. That is why, at this level, the company must focus on improving its perception of and readiness for technological action and on structuring efficient and effective responses to the need for training and research on new technologies, which some employees or areas within the company have already started.

2. At the appreciative level, the company begins to value the need to carry out transdisciplinary processes and internal transversal analysis to improve its appreciation of the advantages, disadvantages, and needs of new technologies and initiates selection and integration studies to take advantage of them in the development of its business model. Likewise, it is concerned with increasing the perception and willingness to act of human resources about new technologies and establishing programs to develop their skills and capacities to select, integrate, and use them in the best way in their management, administration, and production processes. This is because it has begun to interconnect, through technological management activities, the various areas and people who possess the related knowledge, although it still presents limitations in responding to open and complex situations. Hence, the objective at this level is to ensure that the company learns to coordinate technology management and administration activities across various areas.

3. At the organized level, the company has developed a structured architecture aimed at improving its knowledge of new technologies, integrating processes such as resource management, analytical management, meaningful management, and active technology management. In addition, it can now develop analytical activities of perception, readiness for action, guided response, assistance mechanisms, complex responses, adaptation, creation, and innovation, which is supported by the existence of a holistic technology management structure.

4. On the other hand, the company is at the optimized level when it has learned to select, integrate, and use, with a projection of improvement and innovation, the new technologies that its business model and the demands of the economic ecosystem it inhabits have indicated as

necessary to remain current and competitive in the New World Order. By operating at this level, the company manages to open itself to continuous improvement and learns to rely on the knowledge, practices, and skills of its human resources, in combination with permanent updating processes on new developments that appear in the market. In other words, it has managed to fine-tune its capacity for adaptation, creation, and innovation, so that the goal now is to minimize the time it needs to adapt to changes in the ecosystem while increasing its technological management and administration capabilities, which makes it a proactive company instead of a reactive one.

Table 1 describes the levels and characteristics of the operationalization of the companies' maturity model regarding the decision to implement and take advantage of new technologies.

Table 1. Operationalization of the proposed maturity model

	Features			
Levels	*Resource management*	*Analytical management*	*Significant management*	*Active management*
Predisposed	Individuals or areas, as individual agents, develop their resources and responsibilities regarding the management and use of new technologies, which they identify as necessary to perform their tasks. The company as a whole remains on the sidelines of the process, resulting in poor information, content, volume, and innovation.	The company does not have a standard definition for new technologies; each agent defines the ones it needs. As a result, the analytical assessments are deficient and lack applicability. The analyses generated by individual agents lack harmony and compatibility.	Individual agents interpret the need and meaning of the technology, but it is not effectively shared with others, making it ineffective for the company. The result of these actions is procedures without organizational meaning.	Technology decision-making is based on individual hunches because there is no provision for analysis and feedback to facilitate monitoring the effectiveness of actions.
Reagent	In response to the individual results, the company creates centers to manage and administer internal technologies and initiates activities to standardize the technology management process by creating definitions and mapping the new technologies it owns. As a result, local sections are created in which the use and appropriation of technology are integrated within these centers. In addition, human resources innovate and develop tools to take advantage of technology within the center.	The company standardizes the center's procedures for analytical regulation, deployments, and management of the technology repository. This progress contributes to the effective appropriation of technology in each center.	The centers share within themselves the technological meaning, giving rise to a common language related to technology. The common meaning is exchanged, compared, discussed, and fed back, thus improving the indicators for decision-making.	Technological regulation within the centers is based on shared meaning, improving operational efficiency, and internal flexibility. Feedback actions, concerning technological actions, are restricted to the interior of each center.
Appreciative	Alliances between centers are created to promote more effective technology integration and management. By clarifying and unifying definitions and needs among the centers, management efforts are strengthened and the processes involved are improved.	Centers are encouraged to share their analyses with others. The joint analysis is redefined while improving the development and use of new technologies. Repositories of technical analysis are growing in number and sophistication as	Technological meaning is shared and integrated into function manuals. This requires translators to bring order to the syntax and business terminology. The different centers are beginning to take into account and integrate other external meanings in their technological practices.	Alliances between centers generate broader forms of action in the face of new technologies, sharing experiences and broadening the horizon for reacting to contextual actions within and outside the centers themselves.

	A kind of ecosystem is generated between centers in which achievements, needs, and projections are shared around new technologies.	success and failure stories are shared.		The company increases efficiency and effectiveness in analyzing its technology needs.
Organized	The company develops further knowledge around the technologies that may be of interest to it. These are mapped to analyze conscious possibilities of development or acquisition. The company develops a standardized architecture to facilitate the implementation and use of the new technologies it acquires or develops. An almost complete map of the technologies in use is created, thus making it possible to have detailed information about them and their use.	The organization learns to generate sophisticated analysis, based on a better definition of new technologies and their use. The organizational technological repository is structured to promote and share analyses, to which permanent feedback cycles are applied.	The technological meaning generated in the analyses is structured and shared with the other centers. The company learns to manage the language of technology and to foster and promote dialogue between sites based on a unified meaning.	The company designs and executes actions based on the unified technological meaning. A repository of actions is created, which facilitates the reuse of the technical meaning and the results obtained. Constant feedback is effective and helps to improve the assessment of technology needs.
Optimized	The company is committed to keeping its technological mapping updated, investigating internal needs, analyzing external developments, and keeping the related information updated for studies on their acquisition and use. The internal and external technology roadmaps are constantly being refined to keep up with changes in both environments.	The organization strives to find more effective ways to perform technical analysis and better methods to evaluate it. The objective is to rationalize the processes of generation and application of technical analysis.	Processes are put in place to facilitate the ongoing review of the unified technological meaning. Agents are committed to ongoing training and education, developing new skills, and increasing the efficiency of compatible technologies for the entire company.	Actions are scheduled to be reviewed to keep the company up to date with new technologies. The metrics for evaluating technological actions are continuously updated and executed at the pace of the ecosystem's needs. The company creates a repository of technological actions that are regularly updated and consulted.

4. PROPOSED DIAGNOSTIC PROCESS

In addition to the maturity model, a diagnostic process is proposed to make it practical and to determine the level of maturity of the company at a given moment. The objective is to identify the current state, which provides reliable information to make informed decisions about necessary structural improvements. The idea is not to obtain a precise diagnosis of the state of the company, since there are specialized tools for that purpose, but to collect descriptive information that allows placing the company at a maturity level, referring to the technological characteristics of the proposed model. The characteristics of the proposed maturity model are:

1. Management of technological resources. Learning to use technology resources intelligently is imperative for companies in this century because they have become the most costly investments. As a result of the increasing complexity of their administrative structures and the fact that new technologies can be adapted to any business model, technology resource management has become an integral part of any company. Technology resource management is the process of using technology more efficiently and effectively for the business model but

in harmony with other business resources. It is a process that requires analysis, planning, and allocation of resources at the right time and the right cost.

2. Analytical management of technology. Analytical management is an intelligent method and an essential tool for the effective management of new technologies in the current context of business development. It is an integrated framework combining three dimensions and seven factors: 1) Requirements engineering: scope; 2) Technology framework: systems, structure, security; and 3) Technology management: strategy, human resources, skills, and capabilities. The seven factors must be integrated, coordinated, and synchronized to take better advantage of new technologies in the business model [10]. Adequate analytical management of technology drives practical changes based on reliable information.

3. Meaningful technology management. The New World Order environment demands innovative management practices from companies to ensure that business models remain active and for companies to be meaningful in the marketplace. In the New Era, the business world has turned to new technologies, and the digital impact on the relationships of companies with the world, time, space, knowledge, learning, and, of course, with each other. That is why in this century it is not possible to identify a single model for the meaningful management of technology, so companies are forced to develop skills and capabilities to understand new technologies and adapt to their advantages and consequences [11]. In this context, entrepreneurs must consider changes in the administrative paradigm and a new understanding of the technological ecosystem in which their business model is developed, because the accelerated changes require new management practices and human resources processes to efficiently take advantage of new technologies.

4. Active technology management. Active technology management is about managing new technologies to help the company better realize its business model. To achieve this, entrepreneurs must use analytical research, personal judgment, and data science to make decisions about which technology to buy, innovate, or retire. In addition, efficient active technology management helps to shift risk and demystify the use of technology in business. Its goal is to structure scenarios in which better technology performance is achieved so that the company remains competitive in the marketplace. Unfortunately, most companies do not take on this role with determination and find it difficult to consistently overcome mistakes, so they succumb in their attempts to take better advantage of new technologies.

   Active technology management involves: 1) Planning, which identifies the objectives, potential, and limitations of new technologies for the business. In addition to risk and return expectations, innovation needs, the time horizon of use, moral issues, and legal requirements. From there, the company must create market expectations and make adjustments and forecasts to mitigate risk and potential underperformance of the technologies. 2) Execution, which involves implementing acquisition or development and innovation policies. The company integrates its development strategies with market expectations and selects specific technologies to meet the needs of its business model. 3) Feedback, which consists of efficiently and effectively managing the new technologies acquired or developed. This is achieved by rebalancing good performance to ensure that the company remains competitive in the New World Order. In addition, technological performance is evaluated periodically to ensure that investment objectives are met.

In the diagnostic process, these characteristics are used to describe the company's maturity model in more detail. The evolution of each one is analyzed through the maturity levels and its status in each one is described, which allows determining whether or not the company reaches a certain maturity level. Figure 2 shows the relational model of the diagnostic process, in which the characteristics and levels are involved.

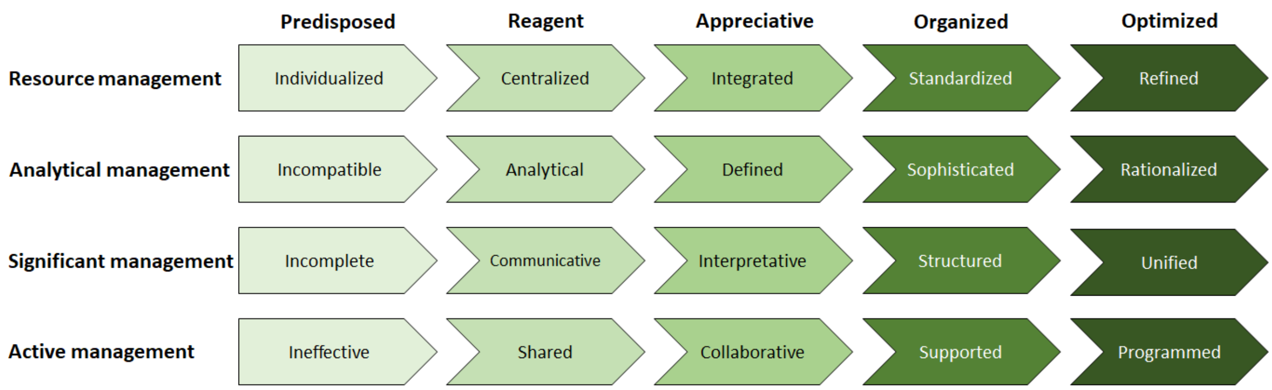

Figure 2. A relational model of the diagnostic process

To determine whether a feature meets the criteria for each level, tools such as questionnaires, interviews, reports, or forms can be applied to the people who manage, own, or lead each process in the system. The objective is to build a holistic view of technology management and to cover the analysis aspects necessary to find the individual maturity level of each characteristic and then the overall level of the company. The structure and content of these consultation tools should be defined by external consultants to avoid biases in the analysis and subsequent interpretation.

5. CONCLUSIONS

The problems related to the maturity level of companies before deciding to select and implement new technologies are related to the concepts of sustainable development and organization, which evolved to a large extent in the wake of the Covid-19 pandemic. The reason is that in the economic recovery, companies realized that they had to be more efficient and effective to adjust their business model to the new technologies, especially from the ecological, technological, financial, and human resource management points of view. In other words, a higher level of maturity leads to a higher level of sustainability.

Another basic issue to keep in mind in this process is related to the challenges faced by companies wishing to take advantage of the benefits of new technologies. Based on the analyses of Bulut and Ilhan [12] and Serna [13], it follows that the preponderant challenges are to perform a proper digital transformation of their processes and to carry out a lean and structured reinvention.

Digital transformation is essential for the implementation of new technologies and must be carried out with a sufficient level of competitiveness in the New World Order in mind. When this transformation covers the entire enterprise, it generates an improvement in sustainability, since there is sufficient data and information to perform an extended analysis of the environmental impact of production and life cycle assessment. This is why, to meet the challenges of selecting and implementing new technologies, companies need to reach high levels of maturity.

The stages of the process proposed in this chapter: 1) reinventing the company, 2) finding the level of maturity, and 3) diagnosing, will allow companies to get closer to a complete vertical and horizontal integration of their systems, without which they may not achieve adequate economic recovery. In vertical integration, they will be able to better connect the internal processes of technology management, while improving communication and business processes with external partners. The recommendation is to structure these tasks as strategic processes, in the form of an action plan and with a vision shared by all areas and people in the company [14, 15].

One issue that emerges from the analysis of research related to the subject of this chapter is that to improve the level of maturity of the company in the challenge of selecting, implementing, and taking advantage of new technologies, it is necessary:

- To face digital transformation as an integral process for the entire company, and avoid falling into the temptation of doing it only in the areas of production and distribution.
- Structure and use quality management in all processes.
- Improve the skills and capabilities of human resources related to the use and innovation of new technologies.
- Develop a comprehensive measurement system for all company processes.
- Improve product design processes by taking into account the characteristics of the post-pandemic context, especially those of clients and consumers.

New technologies have generated substantial changes in many social sectors, especially in the economic sector, and, together with the Covid-19 pandemic, have made it necessary for companies to rethink and implement new business models that will allow them to remain relevant and competitive in the economic recovery. This new reality is both an opportunity and a great challenge since the selection, implementation, and use of new technologies require complex changes in all areas and processes of the company.

The main objective of this work is to help companies determine their level of maturity about the decision to implement and take advantage of new technologies, for which it is proposed to analyze themselves from all functional areas of management: production and logistics, quality, human resources, social and environmental responsibility, innovation and projection. In addition, the idea is to make them aware that, to face the challenges of the New World Order, they need to reach high levels of maturity. Therefore, they are expected to apply the stages of the proposed process related to reinventing themselves, finding their level of maturity, and diagnosing themselves.

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VI
Model for assessing the intention to adopt new technologies in enterprises[1]

The adoption of new technologies helps companies to create a balance between their internal and external complexity, because they innovate production systems, leading them to a decentralized model. The factors and dimensions that a company should take into account in its intention to adopt new technologies are discussed. A model to evaluate this intention is proposed and empirically validated in 32 companies. The results indicate that the intention to adopt new technologies is driven by the market, whether or not there is a perceived strong need to change and build a strong relative competitive advantage.

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1. INTRODUCTION

Production is the basis on which the world's large economies are supported, but demographic changes, globalization, lack of resources, climate change, and intense personalization are some of the global trends that challenge its stability in this century [1]. The reason is that they generate changes that involve volatile, insecure, complex, and ambiguous contexts for companies, affecting their strategic ecosystem [2], so initiatives have been presented that emphasize the manifest need for new production strategies to face these changes and maintain economic growth worldwide [3].

In this sense, the adoption of new technologies can help create a kind of balance between the internal and external complexity of the business environment, by innovating traditional production systems and moving them from a centralized to a decentralized model, which in this decade is known as an advanced production strategy. This is possible because the new technologies (widely known as Industry 4.0) are governed by principles such as modularization, self-regulation, and digital integration, which can be anchored throughout the production model, whether inside or outside organizations.

The implementation of these technologies necessarily induces innovation in the production model, by structuring production processes that are adaptable to consumer demand and integrated along the value chain, the value network, and the life cycle of products.

The point is that while manufacturing is the backbone of large economies such as the USA, Europe, China, and Japan, Small and Medium Enterprises (SMEs) are the foundation on which economies in the rest of the world are built. Due to their structure, SMEs have the advantage of being flexible in their decision to adopt new technologies and adapt to new markets. On the other hand, large corporations are agile and efficient at scale but slow to adapt to innovations [4]. Hence the importance for SMEs to have a model that allows them to analyze their intention to initiate processes to adopt new technologies, taking into account the context of economic reactivation after the Covid-19 pandemic.

New technologies comprise the integration of Cyber-Physical Systems CPS in different business processes, such as production and logistics, in addition to applying the Internet of Things IoT in industrial processes, which generates modifications in the value chain, business model, distribution, and jobs [5]. Although some advanced production strategies require new materials, advanced human-machine interaction, environmental response systems, and virtualization, the general characteristic is that new technologies link physical and virtual systems that use Information Technology IT to innovate production processes. This involves innovation, both for the product and the process, which consists of the integration of conscious and self-adaptive SCP into the production system.

Because the successful adoption and implementation of SCP in any enterprise start from: 1) horizontal integration, through value networks, 2) digital integration, along the entire value chain, and 3) vertical integration and connected production systems [6], then, the innovation of the production process must be structured in a combined way and not separately. This leads to the creation of a kind of smart factory, i.e., an industry in which the complexity of production is modularized, given that it is approached from automatic modifications and in response to changes in its operating environment. Thus, in the smart factory, production efficiency is increased and communication between employees, machines, and resources is improved [7].

Although various technologies have been presented that can be used to implement cyber-physical systems and production processes with IT, such as Big Data Analytics, Cloud Computing, IoT, and virtualization-simulation technologies for training [8], not all of them are at an adequate and useful level of development for all companies [9]. Therefore, SMEs should carefully analyze new technologies before deciding to adopt them; moreover, they should take into account that the maturity models for them are different from those used for large companies because they have specific requirements [9].

In this sense, the Innovation Diffusion Theory IDT [10] proposes that SMEs should evaluate some technical characteristics before adopting a technology: 1) the relative advantage it offers compared to others in the market and the compatibility with their structure and business model; and 2) the efficiency and limitations in terms of complexity and testing capacity, related to the external context: suppliers, customers, standards and projection.

For its part, the Technology, Organization, and Environment TOE framework [11] identifies three important aspects to analyze before adopting a technology: 1) availability, best practices, and equipment, 2) company size, communication processes, and administrative structure, and 3) industry characteristics, market characteristics, and technological support. Likewise, the inter-organizational IO model [12] argues that context shapes organizational structures and actions, and proposes that before adopting a technology one should analyze: 1) perceived benefits, 2) business readiness, and 3) external pressure.

While these models present valid arguments for each of their frameworks, they are not always considered the most appropriate for each particular context and company [13, 14]. Raymond [15] favors the use of the IO framework and states that IDT and TOE need more structure if the company decides to adopt complex and high-impact inter-organizational technologies because almost always the decision is imposed by partners without proper analysis. While Ali et al. [16] prefer the TOE framework and propose to analyze specific product characteristics before adopting a technology: 1) the external context (market uncertainty), 2) the organizational technology (complexity of the IT infrastructure, satisfaction with the current system, level of development and management of the systems), and 3) the administrative system (benefits, barriers, interoperability, and interconnectivity).

In addition, others incorporate inter-organizational aspects and Bayo [17] states that adopting a specific technology is a process of inter-organizational cooperation, therefore, this decision must be a well-coordinated action.

This work, the product of a research process, contributes to the body of related knowledge from the perspective of presenting a model to evaluate the intention to adopt new technologies in SMEs, as well as testing it empirically and analyzing the results.

2. METHOD

In the process of structuring a model to evaluate the intention to adopt new technologies in SMEs, it is assumed that Industry 4.0 consists of integrating the production system and the administrative structure of the company through SCP, under the principles of self-regulation and the advantages of IT. This is made up of a series of constructs, such as: 1) using technologies to manage inbound logistics, the production process, and outbound logistics that autonomously regulate and adapt to changes in the context; 2) monitoring and analyzing in real-time the data and processes of business functions such as administration, research, innovation and development, services, marketing, and sales; and 3) employing an autonomous software system to exchange data between these functions. With the idea of using these elements individually in a query form, they are summarily defined in this research as self-adaptive technologies and digitized processes.

In addition, due to their technological basis, SCP is considered a product innovation, while IT is considered a process innovation, because it combines, aligns, and integrates SCP with the implemented productive and commercial processes. On the other hand, this research involves the proposals of Fichman and Kemerer [18] and Chau and Tam [19], in which it is proposed that in the process of adopting technology, its specific characteristics and some of the existing ones should be added. Therefore, the research method used in this work is structured based on the TOE framework which, to adapt it to the context of SMEs and the peculiarities of the new technologies involved, characteristics (independent variables) from other models are incorporated; while the dependent variable is the adoption intention, assessed according to the Guttman scale.

Many of the specific factors that promote or limit the adoption of new technologies are analyzed in the ECLAC [20] and Patel and Connolly [21] studies, which, although analyzed in broader contexts, are assumed to be transferable to the context of SMEs in any country. Generally speaking, in this environment the main barriers to adopting new technologies are financial, poor IT structure, lack of management support, lack of trained personnel, and resistance due to an insufficient knowledge base about existing technology, standards, and protocols. To structure the model in this research we also take into account the business factors in Table 1 that, in conjunction with the administrative dimensions, determine the intention to adopt new technologies in SMEs.

Table 1. Organizational factors and administrative dimensions

Factors	**Dimensions**
General technology	Perceived complexity
	Perceived integration compatibility
	Perceived relative advantages
	Perceived cost-benefit ratio
In context	Market uncertainty
	Diversity in the cluster
Organizational	Management support
	Satisfaction with the existing system
	Organizational structure
Specific technological	Market transparency
	Safety issues

2.1 Generals' technological dimensions

2.1.1 Perceived complexity

In a logical context, it is expected that the lower the perceived complexity of new technologies, the greater the probability that the company will adopt them. Here, complexity is assumed to be the degree to which the company perceives new technologies as difficult to understand, implement, and use, which almost always generates a negative response to their adoption and which generally arises from a lack of knowledge between the parties.

Because cyber-physical systems are made up of various specialized devices and operate in changing contexts, the adoption process requires analysis of data and IT integration with business functions, the production process, product innovation, and activity considered to be complex. Therefore, it is necessary to establish standards, protocols, and communication models between the parties to achieve smooth communication and high data exchange between business processes. This paper adapts some measures established by other researchers to operationalize this dimension, and starts from the following assumptions:

1. Human capital lacks the knowledge and skills necessary to use new technologies.
2. Integrating new technologies into the current business model and production processes is a difficult task.

2.1.2 Perceived integration compatibility

Although it is a dimension that companies must deal with in all their processes, compatibility is assumed to be the degree to which new technologies can be integrated into the current infrastructure and processes. Some authors conclude that the greater the compatibility, the more likely adoption is [22], although it is true that moving from a centralized to a decentralized production model is a substantial change for SMEs, so it is necessary to be sure that the changes are as compatible as possible with the business culture, which could mitigate resistance to them. Furthermore, the greater the compatibility of new technologies with existing systems, the greater the company's acceptance and ability to adopt them.

Based on the logic that the greater the perceived compatibility of new technologies with existing infrastructure, values, and beliefs, the more likely they are to be adopted, and because traditional systems become strong inhibitors to adoption, compatibility is operationalized in this paper based on these assumptions:

1. The changes that new technologies bring to the company are consistent with current values and beliefs.
2. The changes that new technologies introduced in the company are compatible with the existing IT infrastructure.
3. The changes that new technologies introduced in the company are compatible with the experiences with similar systems.

2.1.3 Perceived relative advantages

The analysis of this dimension is based on the logic that the greater the perceived relative advantage of new technologies for the company, the more likely it is to adopt them. It is accepted that relative advantage is the degree of additional benefit for the SME when adopting new technologies, compared to the established [23], and is also known as perceived benefits [24]. The reason why a company may be driven to integrate new technologies into its infrastructure is to establish a business model that allows it to counter competition, innovate customer service, or structure shorter production cycles. Hence the important to understand the relative advantage, because this increases the likelihood of adopting a technology.

Based on these arguments and accepting the fact that new technologies can provide SMEs with a better competitive advantage, this dimension is operationalized based on assumptions:

1. New technologies will enable the company to better respond to customer needs.
2. New technologies will enable the company to reduce operating costs.
3. New technologies will enable the company to increase its revenues.
4. New technologies will provide the company with timely information for decision-making.

2.1.4 Perceived cost-benefit ratio

The logic required for the analysis of this dimension is that the lower the perceived cost-benefit ratio of new technologies for the company, the more likely it is to adopt them. Of course, one of the most important characteristics for SMEs in these cases is that the technology should be low-cost [4]. Based on the acceptance of the fact that cost is an inhibitor to the adoption of new technologies, due to the lack of economic and human resources that they suffer, this dimension is operationalized based on the following assumptions:

1. The costs of adopting new technologies far outweigh the benefits received.
2. The costs of implementation, maintenance, and support of new technologies are too high for the company's budget.
3. Training human capital to implement and use new technologies is time-consuming and costly.

2.2 Context dimensions

2.2.1 Market Uncertainty

This dimension is analyzed based on the logic that the greater the market uncertainty for the company, the more likely it is to adopt new technologies. This uncertainty originates from technological disruptions, competition, demand volatility, uncertain supply, and policies related to the business context [15] because they come from external organizational factors that affect the way it does business. This induces tension in the internal and external complexity of the company, which it needs to keep balanced before analyzing the adoption of new technologies [25].

Based on the conception that the use of new technologies facilitates the necessary balance because they allow customization and manage market uncertainties, this dimension is operationalized based on assumptions:

1. The market for the products and services offered by the company is stable.
2. Competition for the products and services offered by the company is stable.
3. Demand for the products and services offered by the company is stable.
4. The loyalty of the company's main customers is stable.
5. The price reduction in the context of the company is stable.

2.2.2 Diversity in the Business Cluster

Throughout history, companies have felt the need to cluster, either because of regional affinity, availability of resources, access to energy, or ease of transportation, but with the advent of automation and the improvement of machines, the labor market, and proximity to suppliers became critical. By creating clusters, companies can reduce costs and improve the availability of human capital, as well as access to the necessary knowledge, because people may be attracted to work in the region [24].

This has resulted in firms benefiting from specialized human capital and raw material exchange, something that has been termed specialization externalities [25]. In addition, with the high diffusion of generated knowledge and established competition, innovation is fostered in the cluster.

In this context, the advantage for SMEs is that, unlike large companies that experience greater knowledge leakage, they benefit from the gain of knowledge circulating in the cluster. Based on this reality, the logic used to analyze this dimension is that the greater the diversity in the cluster, the greater the probability that companies will adopt new technologies. Therefore, in this research, the dimension of diversity in the business cluster is operationalized based on the following:

1. The company is located in a related cluster.
2. The companies in the cluster are classified in different economic areas.

2.3 Organizational dimensions

2.3.1 Management support

The analysis of this dimension is based on the logic that when there is the necessary support from management, it is more likely that new technologies will be adopted. It is a fact that management support is an important factor in deciding to adopt a technology, since if management believes in innovation and provides the tools and facilities to carry out the process, an environment of trust is created that makes it possible to overcome the obstacles to adoption [26]. In this paper, the dimension of management support is operationalized based on assumptions:

1. Management will likely want to invest in new technologies.
2. The administration is certainly willing to take risks in the adoption of new technologies.
3. The administration is likely to be interested in adopting new technologies.
4. Management will likely consider adopting new technologies.
5. The administration articulates a strategy for the adoption of new technologies.

2.3.2 Satisfaction with the existing system

In structuring the model, this dimension is analyzed based on the logic that the greater the satisfaction with the existing system, the less likely the company is to adopt new technologies. Reality shows that moving from centralized to decentralized production is a major change for any SME, so it is not surprising that factors such as resistance to change appear, although they mostly arise from a lack of skills or the level of satisfaction with the existing system [27]. Since the perceived complexity dimension already included the factor of lack of skills, for the second one it is assumed that a low level of satisfaction with the existing system generates performance gaps, which should make the company interested in improving it, therefore, this dimension is operationalized based on assumptions:

1. The existing production system is sufficient to meet current needs.
2. The existing IT system is sufficient to meet current needs.
3. The cost-performance ratio of the existing production system satisfies management.
4. The cost-performance ratio of the existing IT system satisfies management.

2.3.3 Organizational structure

The consequences of a centralized organizational structure (pyramidal, hierarchical) on decision-making are highly debatable [28], so in this research, the analysis of the dimension of organizational structure is performed from the logic that, the more decentralized the organization, the more likely that new technologies will be adopted. It is also accepted that to achieve successful adoption of new technologies, which have an impact on various processes in the company, a wide interaction, and collaboration among the actors involved are required. Therefore, a decentralized organizational structure can favor the adoption of new technologies, so this dimension is operationalized based on the following:

1. Decision-making in the company is mainly concentrated in the central administration.
2. The company makes extensive use of multifunctional work equipment to carry out its processes.
3. To fully integrate processes, the company has reduced its organizational structure.

2.4 Specifics technological dimensions

2.4.1 Market Transparency

This dimension is analyzed based on the logic that the greater the market transparency, the more likely the company is to adopt new technologies. Market transparency is understood as the ease of access and availability of information and solutions to implement these technologies and is seen in multinational efforts to circulate information, establish partnerships, and communicate different ways of comparing products from different suppliers. This generates trust and presents the image of a transparent market, which is an indicator of the maturity of the technologies. Due to the importance of this dimension is that SMEs should take time to analyze the technology products on the market because their lack of transparency, standards, and availability are also factors that hinder their adoption [8]. Based on the above, this dimension is operationalized based on the following assumptions:

1. Information about new technologies is widely disseminated.
2. The market for new technologies is transparent in terms of their characteristics.
3. The market for new technologies is transparent in terms of the costs involved.
4. Whether information on standards and protocols for new technologies is widely available.

2.4.2 Safety issues

In the development of this research, the dimension of security issues is analyzed from the logic that the greater the security concerns, the less likely the company is to adopt new technologies. The issue is that the integration of new technologies in the business model generates many doubts about security in the processes because control over data may be lost. Furthermore, during adoption and implementation, sensitive corporate data may have to be shared and, although access is restricted, the risk increases due to the increase in the number of access points. Hence the importance of basing the adoption process on principles of confidentiality, integrity, and availability as a prerequisite [2]. That is why the operationalization of this dimension is based on the following assumptions:

1. The company is concerned about the security and privacy of data and transactions when adopting and implementing new technologies.
2. The company's business partners are concerned about data security and privacy when the company decides to adopt new technologies.

2.5 The *intention to adopt* as a dependent variable

Although in recent decades the development of new technologies has intensified, especially as a result of the entrenchment of Industry 4.0, most of them are still in the evaluation and testing stages, and many of them are not yet beyond prototyping [29]. Due to this, sufficiently robust research results about the adoption process of new technologies in companies have not yet been found. Therefore, in this paper, we first investigate the general intention to adopt new technologies and then, based on the Guttman scale [18], we analyze, using a Likert scale, the first stages of the proposed model, and operationalize them according to:

1. The company is seriously considering adopting new technologies over one to three years.
2. The company needs to adopt new technologies within a period of one to three years.
3. The company is likely to adopt new technologies within one to three years.

3. RESULTS AND DISCUSSION

The form to validate the proposed model was sent to 64 Colombian SMEs in the productive sector located in the cities of Medellín, Cali, and Barranquilla, and responses were received from 32. Table 2 shows the description of these companies, whose size, by several employees, ranges from 20 (12), 30 (10), 40 (5), and more than 50 (5). The logical statements presented in the Research Method were included in the form, to have the participants respond to each dimension on a scale ranging from agreeing to disagree.

Table 2. The production sector of the sampled companies

Sector	Quantity
Automation equipment	2
Agriculture	4
Computers	2
Control equipment	1
Electrical equipment	2
Metalwork	2
Machinery and equipment	3
Engines	1
Mining	3
Transportation	4
Paper production	2
Hardware	1
Mold machining	2
Plastic	1
Other	2

The results of the application of the model are evaluated from the aspects of reliability, convergent validity, and discriminant validity. The first is evaluated by calculating Cronbach's alpha, a measure used to validate the internal consistency of each dimension of the model based on the mean correlations between its constituent items (Table 3).

If Cronbach's alpha value is less than 0.7, it indicates that the statements measure different concepts and are incomprehensible or ambiguous, therefore, according to the results in Table 3 and for the analysis of the validation of the model, only the dimensions of perceived complexity, perceived integration compatibility, perceived relative advantages, market uncertainty, management support, market transparency, and the dependent variables are considered. A principal component analysis (correlation matrix, varimax method) is used to assess the convergent validity and discriminant validity of the other dimensions. After these analyses, the perceived integration compatibility dimension was discarded because it showed many overloads and insignificance (> 0.5).

Table 3. Cronbach's alpha of the model dimensions

Factors	Dimensions	Cronbach's alpha
General technology	Perceived complexity	0.78
	Perceived integration compatibility	0.75
	Perceived relative advantages	0.82
	Perceived cost-benefit ratio	0.61
In context	Market uncertainty	0.67
	Diversity in the cluster	0.30
Organizational	Management support	0.80
	Satisfaction with the existing system	0.53
	Organizational structure	0.84
Specific technological	Market transparency	0.85
	Safety issues	0.64

The results in the other dimensions explain 72% of the variance, have significant loadings in their respective parts, and are not correlated. Heteroscedasticity, the variance of the error term, was tested with Breusch-Pagan, yielding a $chi^2 = 0.18$, which means that the variance of the error terms does not change with the observations. Once the determinants have been validated, a linear regression analysis is performed on the adjusted model for the three scenarios of intention to adopt new technologies: one year (short term), two years (medium-term), and three years (long term) in the SMEs consulted.

In the final regression model, it was found that the market uncertainty dimension is an important factor in the intention to adopt new technologies in the short, medium, and long term in Colombian SMEs. On the other hand, while the perceived relative advantages dimension is important in the short term, the management support dimension is a strong indicator of the intention to adopt in the long term (no supports were identified for the other dimensions).

These results indicate that the intention to adopt new technologies in Colombian SMEs is driven by the market, whether there is a perceived strong need to change and build a strong relative competitive advantage or not, which depends on management support.

According to the results of this research, it is observed that the intention to adopt new technologies in Colombian SMEs is mainly based on external factors, and not so much on internal ones, which is aligned with the results in the work of Moeuf et al. [30], where it was found that the intention to adopt new technologies in SMEs is usually related to cloud computing and, to a lesser extent, in digital transformation, since the objective is to improve their operational efficiency.

4. CONCLUSIONS

This article contributes, on the one hand, to improving the community's understanding of the guidelines by which SMEs decide to adopt new technologies in their processes and, on the other hand, by presenting a model with which to evaluate the intention of adoption.

The proposed model is structured based on factors and dimensions considered from the researcher's experience, the contributions of specialists, and the observations of the companies themselves. Many specific factors that promote or limit the adoption of new technologies in SMEs are analyzed in various studies, but they do not structure a model with which they can be materialized, as presented in this research.

A model is proposed to evaluate the intention to adopt new technologies in SMEs, which is then validated with a form to collect the information, which was answered by 32 Colombian SMEs of different sizes and economic sectors, structured using statements aimed at knowing the valuation that the companies give to certain dimensions regarding their intention to adopt new technologies.

According to the results obtained in the validation of the model, it is observed that the intention to adopt new technologies in Colombian SMEs is based mainly on external factors, and not so much on internal ones.

Although the model was validated in Colombian SMEs, its structure can be adapted to the business characteristics of each country or region, and companies of any size.

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VII

Analysis of the variables that influence people's motivation to take a virtual graduate course in Computer Science

The offer of virtual graduate programs, especially those related to Information Technology IT, is a trend of accelerated growth in this century. However, in light of the results in the literature, it is still not possible to identify the motivations that lead people to enroll in them. In this study, based on the Human Capital Theory, a survey was applied to students enrolled in two virtual postgraduate programs in Computer Science CC, one a master's degree and the other a doctorate, at a public university in Australia. The objective is to analyze, based on the triangulation of demographic variables, educational background, completed studies, and work experience, the motivations that make a person decide to study for a virtual graduate degree in Computer Science. Two motivational tendencies were found: 1) to find a new job or get a promotion, and 2) to develop the skills that the current job requires. Furthermore, although they come from diverse backgrounds, nationalities, ethnicities, and genders, the variable that most influences the decision to enroll in this type of postgraduate program is to develop or enhance the skills required by the labor market of this century. The implications of the findings are also analyzed in terms of the structuring and design of curricula, teaching models, and virtual teaching-learning environments to best serve the diversity of students who enroll.

1. INTRODUCTION

In the last decade, virtual education has expanded at all levels and in all areas, but more rapidly in higher education, which has led institutions worldwide to structure processes to meet this demand [1-4]. This research is oriented to analyze the situation in the area of Information Technology IT, where Computer Science CS is characterized as one of the disciplines with the highest demand, positioning itself as the one that grants the most degrees compared to others in the same area [5]. This is evidenced by the number of undergraduate and graduate programs offered in all countries, both face-to-face and virtual. The issue is that, while virtual graduate programs in QC are recognized as an important educational innovation, little information is found about the actual market and the effect on the employability of graduates. Apart from all this, the interest of the present research focuses on finding out the motivations that people have for enrolling in these postgraduate programs, and whether they perceive them as an educational option that can train and qualify them for competent professional practice.

Traditionally, it is considered that students decide to enter higher education at an early age to obtain a degree at a young age so that they can use this training to practice their profession in a better way and for a longer time [6]. Likewise, some studies affirm that work motivation to develop or potentiate skills, abilities, and capacities through formal programs decreases throughout life, partly because people lose cognitive skills and because they consider that extrinsic rewards do not justify returning or entering education [7, 8]. However, in the wake of the new social reality generated by the Covid-19 pandemic, other research findings challenge these assumptions and reflect a situation in which adults are more interested in enrolling in virtual programs and courses than young learners [9, 10].

Analyses and discussions that attempt to explain this situation vary: 1) from *economics*, in virtual education, costs are reduced and opportunities to enter higher education are expanded [11, 12]; 2) from *work motivation*, in virtual education, teaching models are used that better fit the self-regulated, ubiquitous, and self-paced learning style that adults develop [13, 14]; 3) from *technological developments* and the changing nature of *jobs*, which have created an expanding market for IT professionals and increased demand for professionals with graduate degrees [15]; and 4) from a *relatively high supply of employment* and *salaries* in CC [16]. On the other hand, and because of developments in IT, virtual education allows people to improve their skills and capabilities to meet the demand for jobs in this century.

Because the supply of IT jobs changes rapidly while the number of professionals does not change at the same rate, and because the supply of virtual programs is growing rapidly, it is convenient to identify the value that students place on virtual education because the results will help to close the gap between supply and demand for IT jobs. This research examines the reasons that motivate people's decision to choose a virtual graduate degree in Computer Science and the influence that the institution has on that decision. The results are relevant for the field of educational policies and labor supply, because the labor market in IT is attractive and because virtual education has been modified and technified enough to offer quality programs and teaching models, which improves the opportunities for people to decide to study under this modality. In addition, it is important to know how a person's demographics and professional background influence their motivation to study for a virtual graduate degree in CC.

The study focuses on the Human Capital Theory [17], which explains the individual motivation that leads people to invest in education as an option to potentiate or develop their skills, abilities, and knowledge, with the idea of improving income and other related issues. The objective is to determine the professional benefit that people expect to achieve by studying for a virtual graduate degree in Computer Science at a recognized institution. In particular, the idea they have about their career path after the degree is analyzed, in aspects such as progress, job change, or job stability.

In this regard, more research is needed on the policies that support people's motivation to pursue a virtual graduate degree and their related educational experience. Due to the lack of empirical studies and related literature, this chapter contributes to the development of a research agenda on virtual education at the graduate level by assessing the behavioral patterns and demographic trends of students. The point is that adults studying for a virtual graduate degree have already developed human capital from their previous work experience and training, so it is likely that they give higher priority to the development or enhancement of skills that are relevant to their job [18], a situation that presents institutions with different challenges in terms of the teaching model and curricula to be developed.

2. FRAME OF REFERENCE

Research on *why people decide to enter a virtual graduate program* is often based on the Human Capital Theory, with which they identify the relevant decision factors that lead them to make this decision [19, 20]. In this research framework, it is found that the motivation is for achieving higher income and related benefits, and, on the other hand, a stream of research focuses on analyzing whether they achieve it. From the Human Capital Theory, some researchers try to predict and estimate professional achievement [21], professional success [22, 23], or social benefits [24]. However, paradoxically, there is little research on what role prior experience plays in people's decision to take a postgraduate degree, which is a key issue in the present study.

This previous experience, both in life and in work and academics, is important when evaluating people's decision to enter a virtual graduate program. Although in many countries students, especially young people, move directly from undergraduate to graduate school, for adults it is not always that way, because many enter graduate school after time spent gaining work and life experience [25]. In addition, the supply of postgraduate degrees has become more diverse and extensive in this century [26], which has made many adults want to return to college, and justifies the study of the factors that lead them to make this decision. Hence, these students, who are often working, have developed skills and knowledge different from what they obtained in undergraduate studies and, therefore, are important when choosing which postgraduate degree to study and under what modality.

The results of various investigations and studies suggest that adults return to university for professional reasons, usually because the jobs require them to do so. On the other hand, other research, which delves into the analysis of the motivational and behavioral processes that lead adults to take a postgraduate degree, concludes that these people are very selective and only seek postgraduate degrees that help them develop or enhance the skills they need in their profession [27, 28]. That is, adult professionals only return to university in search of a postgraduate degree that provides them with a clear economic or social benefit.

Some researchers have conducted studies to analyze the motives that lead adults to enter college long after they are working [29, 30], a situation that entails problems because the motivation to do so differs between those seeking an undergraduate degree and those seeking a graduate degree [31]. In any case, research analyzing students' motives for entering graduate school or for changing careers is still scarce [32]. These meager results indicate that students enter a postgraduate degree with the idea of training to apply the skills and knowledge developed directly in their workplace [33, 34]. However, the benefits gained from studying for a postgraduate degree depend on each person's professional and life experience [35]; for example, young people intend to develop skills to perform a job and establish their profession [36], while adults, with previous skills and work experience, do so to update themselves or to aspire to another job [37, 38].

On the other hand, the *motivations that lead people to enter a virtual graduate program in Computer Science* are also diverse, and among them, it can be said that they do so because it is an attractive discipline due to the technological framework in which the 21st century is developing, which supports the reason why the labor supply in IT areas is growing much faster than in other occupations and with better salaries. This reality can be evidenced in research on people's educational decisions, in which their expectations of better salaries and job opportunities take precedence [39, 40].

In addition, the supply of IT jobs is constantly changing, because technological developments require people to develop skills beyond the so-called competencies because in this century they must have an increasingly broad and complete vision of progress [41]. This forces professionals to keep themselves updated and current in new knowledge, and also to expand or develop new skills, which necessarily leads them to seek education and training. According to research in the Theory of Human Capital, the objective of adults when entering a virtual graduate program in Computer Science is to improve their job stability and acquire or develop the skills that the job demands [35].

While this can be assumed as a logical matter, the reality of the 21st century shows that formal education does not necessarily guarantee professional success in new IT jobs [42], while so-called non-formal education, through certifications and continuing education courses, can be more effective in developing the skills and capabilities required in this century [43]. In any case, for many companies, postgraduate degrees have significant value and offer higher remuneration for this type of professional [44], while they are also a promotion mechanism to achieve internal promotions. In addition, people with undergraduate degrees, who lack experience in any of the IT areas, see the study of a postgraduate degree as a springboard to enter a new labor market.

As a result of the above, research that seeks to identify the *motivations that lead adults to take a virtual graduate degree* concludes that, unlike students who go directly from undergraduate to graduate school, in their decision, they take into account variables such as cost and time of dedication [45, 46]. The reality is that virtual graduate degrees are cheaper and, when the teaching model is innovative, the time of dedication is reduced, since the student does not have a regimented schedule, which makes them more affordable for adults who work or have established responsibilities.

Related research evidence that adult learners are more likely to enroll in a virtual graduate degree if they perceive a higher opportunity cost [47], although the demographics of individuals would need to be analyzed before definitive conclusions can be drawn [9].

Researchers on this topic have found that there are still wide differences in what motivates people to enter a postgraduate program, in their previous experiences and the choice of a virtual program [48, 49]; and they highlight that, for many adults, this decision represents a significant resource and a life commitment [50], so before doing so they have to balance personal and work demands. This characteristic marks substantial differences between adults and students who decide to pursue non-formal education or those who go directly from undergraduate to graduate studies.

Unlike research that focuses on analyzing the economic motivations that cause an adult to enter a virtual graduate program at any institution, the interest in this study is virtual graduate programs offered at recognized institutions that have experienced an increase in the number of students in recent years. Moreover, while the advantages of virtual graduate degrees in IT can be ascertained, it is still unclear why adults return to college and why they opt for a virtual graduate degree. In this vein, questions remain that are still not answered: 1) how do the demographics of individuals impact the selection of a virtual graduate degree; 2) why are women and ethnic minorities so underrepresented in CC graduate degrees; and 3) is it true that by accessing a virtual graduate degree, individuals can improve their income and quality of life.

3. METHOD

Data for the data analysis in this research was collected by surveying students in two virtual graduate programs in computer science, one a master's degree and the other a doctoral degree, at a university in Australia. The institution is public, recognized, and accredited, and both programs have received recognition for academic excellence, accessibility, and affordability. The university prioritizes the acceptance of former CC students but also admits those from other programs, to whom a permanency study is applied to select those with the best skills, knowledge, or experience in the field, and to ensure that they graduate successfully. Both programs receive applications from international students and neither requires a certain level of language proficiency, the reason being that the student must have the linguistic ability to understand and comprehend the content of the graduate program in English.

The objective of the survey is to recognize the students' experience in each program through questions that seek to identify: motivation to enter, alternatives considered, and intention to complete the program. The survey was administered to a sample of 1050 randomly selected students, with priority given to women and ethnic minorities. Each student was invited to participate in the study by e-mail, and the survey content, protocol, and informed consent were reviewed and approved by the university's ethics committee.

The overall survey response rate was 75.5% (793) and from these, a consistent data set of 743 observations was obtained for regression analysis. Data collected from the survey were triangulated with institutional and program demographics: country of origin, gender, ethnicity, and date of enrollment. To address the research question, logistic (*logit*) and multinomial logistic (*mlogit*) regressions were applied: with the logit models we examined the motivation to achieve the degree, and with the mlogit we compared the demographic characteristics of the participants. In the analysis, the models were divided by age, with the objective of finding, if they existed, differentiated patterns for adult and young students.

The variables used in the study come directly from the information collected in the survey and the enrollment data. The *dependent variable* is *professional objectives after graduation*. In general terms, any educational process involves an investment in human capital that is only achieved when the expected benefit is greater than the associated cost, and, in this study, *expected benefit* is understood as professional expectations: finding a job (income), achieving a promotion or a new job (progress), or maintaining a job (stability). We also sought to identify whether students perceive the degree as an independent professional investment or as a stepping stone to further study. The question related to the dependent variables was: *after obtaining the degree do you expect* (select one): 1) *to* keep the job, 2) to achieve a promotion, 3) to find a new job, 4) to continue studies, 5) other (specify). The *independent variables* in the study were:

1. *Prior education in Computer Science*: addressed as the undergraduate subject area. Responses were coded into an undergraduate major in the area, a STEM major, and a non-STEM major; non-STEM degrees were used as the reference group.

2. *Work experience in Computer Science*: which serves as a particular measure of human capital for professionals in the area. The survey sought to identify whether the student is or has been employed in CC. Although those who are employed may have acquired work experience that guides their post-degree goals, they may face professional and personal barriers that prevent them from achieving the degree. Students with no experience are the reference group.

3. *Semesters completed*: the results of the research analyzed in the frame of reference indicate that student's professional objectives and interests vary throughout their graduate experience; therefore, to control for these changes, the variable *semesters completed* are included.

4. *Demographics*: In this regard, the variables included: race/ethnicity, age, nationality, with or without a residence visa. The reference group consisted of white students with citizenship.

4. RESULTS

Although the sample selection prioritized female students and those belonging to ethnic minorities, the descriptive results of the study show a marked difference in the number of participants with these demographics. Table 1 shows the descriptive statistics of the variables consulted and shows that, of the sample, foreign students constitute 37%, white 32%, Hispanic 12%, black 11%, and multiracial 7%; that the majority of the respondents are male (66%) and the females are likely Oriental; that 49%) of the students are Australian citizens, 16% are residents, and 35% hold temporary visas; furthermore, that the age of the respondents is between 22 and 68 years, with a mean of 34.5 and a standard deviation of 7.82.

Table 1. Descriptive statistics of the study

	Media	Minimum	Maximum	σ
After obtaining the degree, he expects to				
1. Maintaining the job	21%	0	1	0.40
2. Achieving a promotion	24%	0	1	0.43
3. Finding a new job		0	1	0.49
4. Continuing studies	10%	0	1	0.30
5. Another	5%	0	1	0.23
Previous education in Computer Science				
1. Undergraduate in the area	47%	0	1	0.50
2. STEM Specialty	42%	0	1	0.49
3. Non-STEM Specialty	11%	0	1	0.32
Work experience in Computer Science				
1. Current job	71%	0	1	0.45
2. Work before	9%	0	1	0.29
3. No experience	20%	0	1	0.40
Semesters completed	2.3	0	5	1.80
Demographics				
Woman	34%	0	1	0.47
Age	34.5			7.82
White	32%	0	1	0.47
Oriental	37%	0	1	0.48
Black	11%	0	1	0.31
Hispanic	12%	0	1	0.33
Multiracial		0	1	0.26
Citizen	49%	0	1	0.50
Permanent resident	16%	0	1	0.37
Temporary Visa	35%	0	1	0.48

Although the literature review of the reference framework shows that women have a low interest in pursuing studies in IT areas, in this study it was found that, of the students who previously worked in QC, 6% are men and 15% are women, but who no longer work in the area. On the other hand, about work experience in QC before entering graduate school, 28% (women) and 15% (men) said they had none.

As mentioned earlier, in selecting the sample for this study, priority was given to women and ethnic minorities, so triangulation was made between the variables of Computer Science human capital with race/ethnicity. Table 2 shows that white women, Oriental men, and especially Oriental women are more likely to have no work experience in the field; and white men are less likely to be currently working in the field. In addition, and relation to citizenship, it was found that students with temporary visas and foreigners are less likely to be working in CC in their country of origin.

Table 2. Computational Sciences of Human Capital

Demographics		Previous education			Work experience in QC		
		Computer Science	STEM Specialty	Non-STEM Specialty	Current job	Work before	No experience
White	Man	56%	33%	11%	84%	5%	11%
	Woman	38%	45%	17%	62%	14%	23%
Oriental	Man		56%	5%		5%	
	Woman	38%	48%	14%	50%	16%	34%
Black	Man	49%	38%	12%	78%	4%	18%
	Woman	44%	50%		75%	13%	13%
Hispanic	Man	56%	35%	9%	82%		11%
	Woman	50%	30%	20%		10%	20%
Multiracial	Man	43%	38%		81%	13%	
	Woman	67%	33%	0%	83%	17%	0%
Citizen	Man	47%	38%		76%	8%	16%
	Woman	45%	38%	17%	71%	11%	18%
Permanent resident	Man	45%	52%		74%	4%	22%
	Woman	24%	55%	21%	29%	29%	41%
Temporary or foreign visa	Man	55%	37%	8%	84%	5%	10%
	Woman	39%	54%		46%		39%

Using logistic regression models, we examined the factors that reveal the likelihood of students entering graduate school with any of the options of the *career objective* variable in mind *after the degree* (Table 3).

Table 3. Logistic regression of the variable *after obtaining the degree of expectation*

	After obtaining the degree, he expects to			
	Maintaining the job	Achieving a promotion	Finding a new job	Continuing studies
Undergraduate in CC	1.388	0.983	0.625	2.580
STEM Specialty	1.648	0.740	0.696	2.204
Current work in QC	2.566	2.617	0.314	1.289
I used to work at CC	1.081	1.146	0.950	1.388
Semesters completed	1.251	0.968	0.919	0.898
Woman	1.007	1.233	0.894	0.772
Age	1.028	0.984	0.984	1.026
Oriental	0.691	1.265	1.210	1.228
Black	0.381	1.391	1.253	1.745
Hispanic	0.769	1.405	0.955	1.339
Multiracial	0.787	0.673	1.177	1.817
Permanent resident	0.593	1.086	1.430	1.139
Temporary Visa	0.873	0.575	1.204	2.491

It is observed that, although previous education in QC has no significant effect on any of the models, work experience does. Those working in QC are more likely to seek to keep the job or get a promotion, and less likely to find a new job in the field than students with no experience. On the other hand, those with more semesters in graduate school are more likely to want to keep the job and less likely to want to find a new job.

Regarding statistics related to student demographics, the results show no difference in the likelihood of seeking any outcome after obtaining the degree. Black students are less likely than white students to want to keep their jobs, and students on temporary or overseas visas are less likely than Australian citizens to want to achieve promotion but are more likely to seek further study. Looking at age, it was found that the older the age, the more likely students are to want to keep their jobs.

Another characteristic of the students that influences the level of importance they attach to obtaining a virtual graduate degree is related to the stage of life in which they do it. For this triangulation, the models in Table 3 were run, considering the data: 22 < age < 34 and age > 35 years, because it is expected that at this age they already have some time working, the results are shown in Table 4.

Table 4. Triangulation between variables *after obtaining the expected grade* vs. average *age*: Logistic regression

	22 < age < 34				**age > 35**			
	Maintaining the job	Achieving a promotion	Finding a new job	Continuing studies	Maintaining the job	Achieving a promotion	Finding a new job	Continuing studies
Undergraduate in CC	0.940	1.567	0.698	1.714	2.055	0.588	0.512	5.894
STEM Specialty	1.064	0.993	0,85	1.444	2.686	0.535	0.524	4.915
Current work in QC	2.756	3.374	0,289	1.178	2.553	1.931	0.348	1.768
I used to work at CC	1.281	2.007	0,977	0.307	1.088	0.686	0.923	3.837
Semesters completed	1.312	0.899	0,917	0.871	1.208	1.028	0.924	0.921
Woman	0.974	1.250	0,898	0.873	1.005	1.353	0.905	0.513
Oriental	0.916	0.948	1,153	1.537	0.443	1.868	1.340	0.936
Black	0.122	1.135	1,545	1.971	0.699	1.924	0.945	1.443
Hispanic	0.741	1.591	0,865	1.229	0.844	0.896	1.149	1.371
Multiracial	0.630	0.418	2,573	0.597	0.881	1.222	0.270	3.225
Permanent resident	0.338	1.042	1,985	1.247	0.838	1.005	1.099	1.066
Temporary Visa	0.759	0.581	1,336	2.391	0.796	0.748	1.069	2.050

It is observed that younger students with a job in CC enroll with the idea of getting a promotion, and older students, with the same job, do not have this objective. Students with jobs in QC are equally likely to keep them regardless of their age, as is the probability of finding a new job in the field.

In contrast, triangulating the race/ethnicity variable found different results as, among older adults, Orientals are less likely than whites to want to keep their job, and blacks are less likely to want to stay in their current job; while young multiracial students are more than twice as likely as whites to want to find a new job in CC. Meanwhile, young permanent residents are almost twice as likely as citizens to find a new job; students on temporary visas and residents abroad are more likely than citizens to continue their studies, but less likely to want a promotion.

Another analysis carried out with the data was to identify the probability that students, *after obtaining the degree*, value one option more than the others. For this triangulation, multinomial logistic regressions (*mlogit*) were applied to make the necessary comparisons, for which base case 0 was taken as the potential target and case 1 as the alternate target (Table 5).

Table 5. Triangulation between options *after obtaining the expected grade*: Logistic Regression

Base category	**Maintaining the job**			**Achieving a promotion**		**Finding a new job**
Comparison group	Achieving a promotion	Finding a new job	Continuing studies	Finding a new job	Continuing studies	Continuing studies
Undergraduate in CC	0.757	0.579	1.815	0.765	2.397	3.136
STEM Specialty	0.531	0.543	1.388	1.022	2.612	2.557
Current work in QC	0.957	0.246	0.559	0.257	0.584	2.273
I used to work at CC	1.040	0.938	1.239	0.902	1.192	1.321
Semesters completed	0.820	0.794	0.762	0.968	0.929	0.960
Woman	1.174	0.929	0.791	0.791	0.674	0.852
Age	0.967	0.969	1.002	1.002	1.036	1.034
Oriental	1.578	1.491	1.612	0.945	1.022	1.081
Black	2.772	2.533	3.595	0.914	1.297	1.419
Hispanic	1.549	1.174	1.570	0.758	1.013	1.337
Multiracial	0.884	1.333	2.086	1.507	2.359	1.565
Permanent resident	1.639	1.895	1.732	1.156	1.057	0.914
Temporary Visa	0.736	1.255	2.524	1.705	3.428	2.011

In contrast to the previous analysis results, significant differences are found in these results. Students with a CC undergraduate degree are three times more likely to want to continue their studies than to find a new job, which is more relevant for non-citizen students. Respondents with a current CC job are less likely to find a new job than to get a promotion or keep the job and are more likely to want to continue their studies than to find a new job. But CC experience does not seem to influence the relative likelihood of keeping the job, getting a promotion, or continuing studies, relative to the other options.

A striking feature in terms of demographics is that the best results are specific to black students, as they are more likely to want to find a new job, get a promotion, or continue their studies after obtaining the virtual degree than to keep the job. Regarding citizenship, it was found that permanent residents are more likely to find a new job at CC than to keep the job; while temporary residents and residents abroad are between two and four times more likely to want to continue studies than any other option and are more likely to seek to find a new job than to get a promotion.

On the other hand, it was found that the older the respondent, the more likely he/she is to want to keep the job than to get a promotion or find a new job; while the older the respondent, the more likely he/she is to continue studies than to find a new job.

5. DISCUSSION

The continuing and accelerating developments in IT in this century create a context of opportunities for postgraduate studies for young people, and for adults who can adapt and use them in their jobs. Universities have also become aware of this potential student market and are structuring and offering postgraduate degrees, both face-to-face and virtual, to help close the gap between the demand and supply of trained professionals in these areas. But it is a complicated process, because along the way they have to understand and comprehend the objectives that students seek when taking these programs, especially in the virtual modality, as well as the motivations that lead them to make the decision.

This research analyzes the advantages of pursuing a virtual graduate degree in Computer Science, an emerging degree option that has become a potential option in the wake of the Covid-19 pandemic, but with little analysis in previous research. Because of this, it is not surprising that, in the results, it is identified that working adults decide to enroll in a virtual graduate degree in CC because of their need to adapt to the new context, but with different goals.

The offer of virtual graduate programs makes it easier for people to achieve goals such as finding a new job and acquiring the skills required for new jobs [51]. When students with an undergraduate degree in CC pursue this type of postgraduate degree, they gain competitive advantages that make it easier for them to adapt to the labor market, find new jobs, or achieve a promotion, in addition to aspiring to better salaries. The findings in this study reflect the interest of most students in achieving a promotion or a new job after the degree, but, on the contrary, for some of the participants achieving a graduate degree is less important for advancement in the labor market, for example, students with extensive work experience in QC are less likely to want to achieve promotion than to keep the job or find a new job.

Another characteristic of the results is that, at an older age, it is less important to achieve a promotion or find a job than to keep the job, something that is worrying, because although it was found that adults study a postgraduate degree to improve or develop their skills, it is still not clear what use they make of the degree after graduation. The results seem to show that developing or enhancing skills not only helps them to find a new job or get a promotion but also to keep the job since they use them to be updated and relevant or to aspire to intrinsic distinctions that are not yet fully understood. Hence the importance of extending the research to analyze these motivations, to reveal how intrinsic and extrinsic motivational aspects influence the decision to enter a virtual graduate program, including the different ways in which adults adapt to this type of education.

The focus of this research on the development of human capital in Computer Science reflects unique and relevant characteristics, because, while in the general context of Information Technology professionals are placed in multiple jobs in different areas, due to the increase in demand for new contextualized skills, the demand for trained human capital in CC is also growing. The results of this study suggest that many students want to change careers, which is a factor that universities can use to motivate them to enter the field of QC and offer them opportunities to pursue both undergraduate and graduate degrees.

It was also found that institutions face the challenge of having to select graduate students well because there has been an increase in the number of students, with undergraduate degrees in different disciplines and no QC experience, who want to enter these programs. While a virtual graduate degree breaks down the barriers to entering graduate education, the background of the students could be a factor in higher attrition or not having clarity about what to use the degree for after the degree.

Due to the current diversity in the industry-profession relationship, there is also a wide demographic diversity among students and professionals, so this study analyzed the motivations that lead students, from all demographic groups included, to take a virtual graduate degree in QC. It was found that, of the sample, more women than men enrolled in the graduate program in QC, but their undergraduate degree was not in the field and they did not have work experience in the field. On the other hand, it is more likely that blacks are motivated to study for a graduate degree to get a promotion or find a new job than to keep their job.

However, we did not find a marked difference in the motives for entering graduate school between men and women or between Hispanics and whites, which is noteworthy because, as described in the framework, other researchers have found gender differences in this regard. Thus, further research is needed to fully understand the influence of gender and ethnicity on the decision to take a virtual graduate program.

6. CONCLUSIONS

The diversity of students and their motivations for enrolling in a virtual graduate program in QC pose challenges as well as opportunities for both institutions and faculty. Since it has been shown that this type of program attracts students with diverse demographics and from areas other than QC, it is necessary to structure and design them to satisfy all of them, but more importantly, to meet their expectations and motivations for taking them. Hence the importance for institutions to recognize students long before the programs begin, because this provides them with the necessary information to structure a curriculum and a teaching model adjusted to their characteristics [52].

This study found that adults are more consistent in wanting to learn, so if they are offered a relevant, up-to-date, and practically applicable curriculum, they are more likely to be motivated to complete graduate school. However, it was also determined that the work-relevance relationship is defined according to employment status, industry sector, and experience, versus the motivation that leads them to enroll. In analyzing this situation, a new challenge is identified, since the program must be structured to attract young students with undergraduate degrees in QC, as well as adults with experience and clear motivations, and if the curriculum is not sufficiently attractive, they may perceive it as too basic or outdated.

This situation should cause institutions to look for ways to ensure that young students complete graduate school while keeping adults motivated. The point is that, if the program does not take this into account, students with undergraduate degrees in non-STEM areas and no work experience in QC will become frustrated, and will most likely not complete the graduate program. But, if the content is very basic and the CC experience and skills of the adults are not taken into account, they are also likely to drop out. This means that the institutions have to carry out in-depth analyses of variables such as previous studies, experience in the area, and age, and structure induction courses for the graduate program in such a way as to achieve a leveling in which they develop some fundamental skills and knowledge for the program.

These actions cannot guarantee the permanence of students, because in parallel other variables affect their decision to enter or remain in graduate schools, such as language, family, and salary, among others. But neither does it mean that a good professional experience and an undergraduate degree in the area are sufficient for the student to develop the skills he/she is looking for in graduate school. The reason is that their knowledge may be outdated or not adequately understood, which becomes a barrier for them to progress in their studies and to feel included in the curriculum. Therefore, the professors must evaluate to identify what they know, how they know it, and what they use it for, and with the results design a teaching model that will break down myths and provide effective knowledge.

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VIII

Why don't high school students prefer STEM careers? An analysis of their perceptions

The objective of the research was to analyze the appraisals of high school seniors, who participate in programs in which they take higher education courses, and why they do not choose to pursue careers in Science, Technology, Engineering, and Mathematics STEM after enrollment. Data were collected from 368 participants using a cross-sectional study approach and a pre-experimental research design with documented limitations on threats to internal and external validation. The findings show that they have little interest in pursuing careers in these areas; furthermore, factors such as family support and encouragement from motivating teachers arouse various levels of enthusiasm and questions that may or may not lead them to choose these careers.

1. INTRODUCTION

In this century, the world is increasingly dependent on skilled labor in areas such as science, technology, and engineering to meet the demands of modern society and the development and protection of the planet [1]. As technological development increasingly covers human activities, the demand for these professionals will be determined by the number of graduates and the quality of education in these areas [2].

In the second half of the last century and due to the boom in technological discoveries and developments, the world experienced a wide demand for careers in science and technology, which determined an increase in the number of graduate students, as well as the expansion of economic development and a wide scientific and technological diffusion [3]. But, by the end of the century, researchers and university administrations noticed an increasing decrease in students interested in these careers [4], at the same time as low quality in the education of graduates.

In part, this was due to high school students losing interest in careers in science and engineering, preferring more social or human areas. In addition, many countries urged their universities to offer training in STEM areas, which led to an oversupply of careers, although without the proper vocational motivation or the quality of education that was needed [4], which could be evidenced in the results of various tests, such as those of the Program for International Student Assessment PISA, where students do not achieve satisfactory grades in science, technology, and engineering [5]. On the other hand, less than half of the students who take careers related to these areas graduate, which represents a wide gap between the demand for these professionals for the development of the world and the total number of graduates [6].

On the other hand, although the labor supply is currently global, numerous jobs in science and engineering remain unfilled around the world, either because of a lack of qualified professionals or because candidates simply do not apply [7]. This scenario has led governments to develop initiatives to improve this workforce because the priority for researchers, professionals, and administrators is to convince high school students to take these careers and, for those who start them, to complete them [8], in addition to improving the quality of education provided at all levels of the education system [9].

The literature contains several papers addressing the issue of high school students' preferences for choosing a university career in science or engineering, with results that should be of concern to governments, universities, and industry alike. For example, Drew [10] found that more than 50% of students who planned to take these careers ended up selecting others or withdrawing from them in the first year. Among the reasons for not completing their studies are: that the introductory courses do not inspire and that they possess low preparation for completing mathematics courses. This reinforces the results of the study by Garg and colleagues [11], who found that students' high school experiences in math and science courses strongly influence their career choices.

For their part, Sadler et al. [12] found that, at the end of high school, the probability of students taking careers in science or engineering is 2.9 times higher for males than for females. This is because they consider science and technology to be irrelevant to their future career goals, preferring, for example, social programs. Furthermore, according to the U.S. National Center for Education Statistics [13], students from low-income and cultural minority backgrounds fail to adequately develop the skills and abilities in science, technology, engineering, and mathematics that are required to study related careers.

According to the results of the studies by Serna and Serna [4, 14], there are a variety of reasons why students do not take careers in science and engineering, such as: that there is an inadequate interpretation of their meaning by industry, the State, academia, and society; the industry is not clear about the functions that an engineer performs; academia does not efficiently serve the needs of the sector and seems to be in a direction contrary to the development of the globalized world; and society is unaware of these professions and values occupations such as music, television, modeling, and sports more highly.

These researchers conclude that this situation has generated a shortage of trained professionals and that universities lack the dynamism to update programs, professors lack professional experience and students lack more training in mathematics and science.

On the other hand, few studies analyze the effectiveness of programs that allow high school students to take college courses in science and engineering. If the goal is to make *them fall in love with* these careers and help them adequately develop their math and science skills, it is necessary to go beyond mere academic achievement and study variables such as those related to student engagement and life choices since high school. In any case, research has been conducted on the various factors that influence students' decision to study a career in science or engineering [15, 16] that support the focus of this study.

In addition, although programs in which high school students can take college courses have become increasingly common, little is known about the ultimate career choice preferences of these students [17]. Although it cannot be demerited that these programs originated with the idea of offering training in one or more areas of study in science or engineering, to train students to supply the shortage of jobs in these areas, it seems that they are not achieving this goal to a large extent, because the courses are difficult and, many times, do not relate to the reality that the professional will find in the market.

What is needed is to address the comments made by students about participating more in practical activities, to awaken in them the curiosity to be better every day, and to choose with greater confidence a university career in science or engineering.

2. METHOD

Three research questions were addressed in this study: 1) What are the judgments that high school students take into account when selecting a university career related to science or engineering? 2) To what degree do these judgments depend on attributes such as gender, size of the institution, and culture of origin? 3) What are the main influences on their decision to take or not to take these careers?

2.1 Research design

The cross-sectional study approach [18] was selected, where the current point time of data is taken at a single point in time for the group surveyed and inferences are made about the population of interest. This is a pre-experimental research design with documented limitations on threats to internal and external validation [19]. Data were collected in 368 surveys of high school seniors concurrently participating in college programs where they take courses in science and engineering. The surveys were administered online as part of introductory courses for the 2019-2020 academic year in Germany and England. In addition, students' gender, the size of the home institution, and culture of origin were probed.

2.2 Instruments

Two instruments were applied: 1) the *semantic survey* [20], and 2) the *professional interest questionnaire* [21]. The first was adopted as a questionnaire of attitudes towards Information Technologies, from which the adjectives most related to the research objective were selected and incorporated as descriptors for respondents to reflect their perceptions about science, mathematics, engineering, and technology. In addition, an option was included to assess their interest in a career in science or engineering. Internal consistency reliability [22] presented a range from Alpha = 0.87 to Alpha = 0.94 for the participant group, which falls between the *very good* and *excellent* ranges.

The second instrument, the professional interest questionnaire, is Likert-type, from 1 = Strongly disagree to 5 = Completely agree, and consisted of questions on three scales adapted from Bowdich [21]. In this case, the Alpha ranged from 0.72 to 0.94, which places the reliability between *respectable* and *excellent*. In addition, two open-ended items were added to inquire about the factors that arouse students' interest in a career in science or engineering and to collect students' opinions about how education in these careers could be improved.

For the research questions, items were adapted from the work of Serna and Serna [23], whose survey inquired about the reasons why high school seniors do not select a career in science or engineering, with the same rating on the Likert scale.

3. RESULTS

The average deviation scale in the surveys is shown in Table 1; the reader should note that the semantic differentials are valued on a scale of 1 to 7, from 1: *Strongly disagree* to 7: *Completely agree*, while for professional interest a Likert scale was used: from 1: *Strongly disagree* to 5: *Completely agree*. Thus, in the semantic survey, science obtained the most positive perception (5.22 / 7.0), while engineering obtained the least positive (3.18 / 7.0). Similarly, in the professional interest questionnaire, the perception of science is better than that of engineering.

Table 1. Average perception scale

	N	**Media**
Semantic Survey		
Science	368	5.22
Technology	368	4.32
Engineering	368	3.18
Mathematics	368	3.68
Professional Interest Questionnaire		
Science	368	3.05
Engineering	368	2.18

On the other hand, regarding the items of the questionnaire of professional interest in science (Table 2), the respondents are more in agreement that scientists contribute significantly to human development (4.59 / 5.0), and that achieving a degree in science can be a great challenge (4.38 / 5.0) and that a degree in science would allow them to work in transdisciplinary teams (4.30 / 5.0). However, they have a low perception that they will be respected for their work as scientists (3.39 / 5.0) and that they will be successful professionals (3.41 / 5.0).

Table 3 presents the average assessment of professional interest in engineering careers. The results validate the mean perception of Table 1 about both career areas, i.e., engineering has little interest as a career that students want to pursue. The items with the least interest are that they will be respected as engineers (2.92 / 5.0), that they will make substantial engineering contributions (2.98 / 5.0), and that families encourage them to pursue engineering (3.0 / 5.0).

Table 2. Average evaluation of professional interest in sciences

	N	**Media**
Wants to start a career in science	368	4.10
The family circle is pleased that I am taking courses in science.	368	3.50
I would enjoy taking a career in science	368	4.03
The family encourages him to study science	368	3.95
You want to specialize in an area necessary to pursue a career in science.	368	3.80
Take courses that will prepare him/her for a career in science.	368	3.98
You will be a successful professional to make substantial scientific contributions.	368	3.41
You will work in an area related to the sciences	368	3.65
You will be respected for your work as a scientist	368	3.39
A degree in science would allow you to work in transdisciplinary teams.	368	4.30
Scientists make a significant contribution to human development	368	4.59
Achieving a degree in science can be a big challenge	368	4.38

Table 3. Average assessment of professional interest in engineering

	N	**Media**
Wants to start a career in science	368	3.12
The family circle is pleased that I am taking courses in science.	368	3.01
I would enjoy taking a career in science	368	3.01
The family encourages him to study science	368	3.00
You want to specialize in an area necessary to pursue a career in science.	368	3.05
Take courses that will prepare him/her for a career in science.	368	3.02
You will be a successful professional to make substantial scientific contributions.	368	2.98
You will work in an area related to the sciences	368	3.02
He will be respected for his work as a scientist	368	2.92
A degree in science would allow you to work in transdisciplinary teams.	368	4.15
Scientists make a significant contribution to human development	368	3.99
Achieving a degree in science can be a big challenge	368	4.25

3.1 Research questions

1. The first research question was focused on knowing the appraisals that students take into account when selecting a university career related to science or engineering. Table 4 presents the results of the items offered as assessment options to high school seniors as to whether or not they take them into account when choosing careers in science or engineering. The Likert scale applied is 1. Strongly agree, 2. Agree, 3. Neither agree nor disagree, 4. Disagree, and 5. Strongly disagree.

Table 4. Appreciation for pursuing a career in science or engineering

	1	**2**	**3**	**4**	**5**
Recommendation of family members or professionals in the area	235	35	38	2	58
Of those who enter, few finishes	16	272	31	26	23
Scientists and engineers are offered low salaries in the marketplace	278	26	27	15	22
They are careers with many demanding courses in mathematics.	83	51	203	21	10
The profile offered by universities is confusing	180	122	29	23	14
The media presents a scientific and engineering reality that discourages the reader.	152	131	47	16	22
There are too many sciences and engineering-related programs on offer	170	43	89	48	18
The way science and engineering programs are offered is confusing	262	47	25	14	20
A future for professionals in science or engineering is not perceived to be adequate.	84	95	128	33	28
High school graduates have insufficient foundation to pursue a career in science or engineering	47	44	248	19	10

2. The second research question sought to determine the students' appraisals in terms of disaggregating variables such as gender, size of the institution, and culture of origin. Of the 368

participating students, 120 were women and 248 were men and, as can be seen in Table 5, for the semantic survey, women had higher ratings than men in terms of interest in studying a STEM career; while, in the professional interest questionnaire in the part of specific careers in science or engineering, men had a greater interest in one of them.

Table 5. Results of the analysis of the appraisals by gender

	N	Women	Men	% Women	% Men
Semantic Survey					
Want to take a STEM career	368	120	248	70%	38.7%
They do not want to take a STEM career				25%	60%
Professional Interest Questionnaire					
They want to study a career in Science	368	120	248	23%	62%
Want to study a career in Engineering				7%	26%

They were also asked to indicate the size of the institution in which they are completing high school. The options included the categories of *Small* (less than 1000 students), *Medium* (between 1000 and 2000 students), and *Large* (more than 2000 students). As shown in Table 6, the ratings of the 246 students from Small institutions, in terms of wanting to study a STEM career, were higher than those from Medium (99) and Large (23) institutions. However, students from Medium institutions are more inclined to study a career in science or engineering.

Table 6. Results of the analysis of the appraisals by the size of the institution of origin

	N	Small	Median	Large
Semantic Survey				
Want to take a STEM career	368	72%	36%	12.5%
They do not want to take a STEM career		25%	61%	80%
Professional Interest Questionnaire				
They want to study a career in Science	368	37%	45.5%	25%
Want to study a career in Engineering		28%	39%	0%

On the other hand, the cultural distribution of the population was represented by Asians (215), Caucasians (77), Hispanics (48), African Americans (19), and others (9). An analysis of variance by ethnicity was done for the combined group and significant differences were found in the areas queried. While African American students have a high willingness to study a STEM career overall (89%), Hispanics are more inclined toward technology (65%), and Asians toward mathematics (71%). In addition, Caucasians report a high interest in studying engineering (90%), while Asians are more inclined toward science (61%).

3. The objective of question three was to examine the main influences on students' decision to take a career in science, mathematics, technology, or engineering, for which a content analysis [24] was applied to classify the responses. It was found that the main reasons were 1) recommendation from parents or a close relative (34%), 2) motivating teachers and considering an example to follow (21%), and 3) natural inclination or self-seeking (12%). Others mentioned were science and math courses guided by motivating teachers (8%) and science fairs, exchanges, and competitions (4%).

4. DISCUSSION

Among the different findings in this study, it is possible to analyze aspects such as that the results related to gender are not consistent with other reported trends, for example, Sadler et al. [12] where women show low inclinations to pursue a university degree. In general, in the results of this research women manifest higher inclinations than men to pursue university studies and in semantic perceptions as a life option. One striking issue is that they are less positive than men about science and engineering. This situation requires further research to elucidate the issue, because these results may reflect trends in the new generation toward university studies in STEM areas.

Another aspect that is evident in the findings implies that students who enroll in university course programs, at the same time that they finish high school, acquire a different interpretation of reality concerning their disposition toward science, engineering, technology, and mathematics. This may be because in the college environment they discover that, to be successful in these areas, more hard work is required than in high school. However, because only seniors participated in this study, additional studies would need to be conducted to confirm this trend from the junior year onward.

What was found in this research about the ethnicity of the participants renews the results of other studies and reports, because they show a lack of interest and low representation of ethnic groups in high school for taking careers in science, engineering, technology, or mathematics [25, 26]. In contrast, in this study, ethnic groups considered to be minorities expressed a high willingness to pursue these careers: African Americans for STEM careers in general, Hispanics for technology, and Asians for mathematics. In addition, Caucasians report the highest disposition to study engineering, and Asians for science. These findings are noteworthy because other studies have found a significant gap between these ethnic groups in math and science achievement after entering college [27]. In this case, further research is needed to determine whether the differences found between wanting to study a career in science or engineering versus college achievement outcomes are related to students' ethnicity.

On the other hand, findings on the size of the institution where they are completing high school show that students from smaller institutions are more willing to pursue careers in STEM fields. In most studies comparing students' college attainment against the size of their high school institution, graduates from smaller ones have been found to have a higher academic achievement [28, 29]. This should merit further analysis, because it could be that the study environment at larger institutions limits or directs students' dispositions for taking science or engineering majors, with the already demonstrated results in terms of their college performance.

In parallel to the research questions that guided this study, students were asked to describe how they thought education in STEM areas could be improved. The findings show creative suggestions and concrete opinions: more practice is needed, but it should be attractive and based on problems that can be seen in reality; more related courses in high school, but with content, methodologies, and didactics that generate concerns that they can answer themselves; professional education from school; classes should be more dynamic, with examples and real-world problems; and passionate teachers, motivating and permanently qualified. These suggestions are not far from the results found by researchers about the fact that students achieve better results when, from the early stages of their cognitive development, they are exposed to formative processes in scientific research.

Also, at those ages, they have curious minds and show natural inclinations towards engineering processes: designing, building, and disassembling things just to learn about how they work. The suggestions raised by students in this and other studies, regarding how to improve education in these areas, could be incorporated into the research agendas of states and universities, to find measurable impacts through experimental paradigms. In this regard, Heilbronner [8] found that one of the determining factors for a student to choose a career in STEM areas is the positive psychosocial ones, which allow them to build a positive and useful idea of studying careers in science or engineering.

In this study, it was found that students, in the dispositions and comments, demonstrate that factors such as family support and the encouragement of motivating teachers awaken in them various levels of enthusiasm and questions, which direct their choice of a university career. In this order of ideas, a pending issue is to achieve the promotion and the need for professional profiles in science and engineering in high school students, because that is the hope of humanity in the 21st century in the face of the lack of professionals in STEM areas.

Limitations of the study

In general, the pre-experimental design adopted for this study offers some limitations that should be mentioned: 1) the data were collected at the beginning of the academic year, but had it been conducted at a different time the results might have been different; 2) many of the participants were just having their first experience in university studies, so they might have very vague ideas of the issues that were inquired about in the survey; 3) the majority of participants were of Asian origin, so the dispositions collected may not be representative of majority groups in each country; 4) although the basis of the study was a convenience sample, this is of no concern to the team because the total number of students who responded to the survey corresponds to 96.8% of those enrolled in university programs, in which they take higher education courses while completing their high school studies.

5. CONCLUSIONS

Data were collected through surveys of 368 high school seniors, whom themselves participate in university programs in which they take higher education courses in science and engineering.

The responses were analyzed to compare and contrast the dispositions of these students to pursue college careers in STEM areas, as well as to discuss the level of incidence, in their decisions, on variables such as gender, ethnicity, and size of the institution in which they study high school.

The findings confirmed some of the researchers' expectations and results of similar studies, in the sense that students have a low valuation for careers in science and engineering; but the differences between men's and women's intentions to take a university degree are surprising.

In addition, the results convinced the work team of the need to structure and carry out research processes on issues that were not covered in this work. Here one could mention: to elucidate whether these results may reflect trends in the new generation toward university studies and to determine whether the differences found between wanting to study a career in science or engineering versus university performance results have any relationship with the ethnicity of the students and the size of the institution where they finished high school.

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IX
Epistemological construction of Transdisciplinarity: A way to understand the New Era

The problems of today's society are increasingly complex, and finding solutions to them will be more and more difficult, so trying to understand, model, and solve them only with the approach of an isolated discipline is an almost impossible task. The Transdisciplinarity approach emerges as a support to carry out this task because its objective is to integrate the different levels of reality so that scientists can envision equally complex solutions. This chapter presents a conceptual journey from disciplinarity to transdisciplinarity and describes the epistemological construction of the latter, mainly from the contributions of Basarab Nicolescu and Edgar Morin, as a basis for educating and training professionals who will have to solve complex problems in the New World Order.

1. INTRODUCTION

Science is a body of knowledge obtained through systematic and structured observation and reasoning from which general principles and laws are deduced. *Normal science* is defined by Thomas Kuhn [1] as the pursuit based on one or more scientific achievements that a particular community recognizes over some time as a basis for subsequent practice. This concept of science envisages a period in which scientific activities take place within the framework of the predominant paradigm. But science, because in many cases it is evidence, must go beyond facts to be clear, precise, and communicable. On the other hand, a discipline is a category in which scientific knowledge is organized and which establishes the division and specialization of a work that responds to the diversity of the areas covered by the sciences. Although a science encompasses a larger whole, a discipline naturally tends to autonomy and to the delimitation of its boundaries, the language, and techniques it has to develop or use, and, possibly, its theories [2].

When analyzing today's society, it is possible to observe a series of problems that are defining this century, such as water, forced migrations, poverty, environmental crises, violence, neo-imperialism, and the destruction of the social fabric, and one must necessarily conclude that none of them can be adequately addressed from the sphere of any specific individual discipline because they represent transdisciplinary challenges. The situation cannot be resolved, as is often attempted, by creating supposed teams made up of specialists in different areas around a given problem. With such a mechanism one can only aspire to achieve an accumulation of visions that emerge from each of the participating disciplines. But a synthesis of integration is not achieved through the accumulation of different brains, it must occur within each of them.

On the other hand, in the last decade, the number of complex societal problems has increased and the technical knowledge and understanding of science and engineering needed to address and mitigate them are rapidly evolving. The world is becoming increasingly interconnected and new opportunities and highly complex problems are emerging that are only recently beginning to be identified [3]. When these problems are not solved timely and correctly they become crises, such as energy shortages, pollution, transportation, environment, natural disasters, security, health, hunger, and the global water crisis, and threaten the very existence of the world as it is known. That is why none of these complex problems can be understood from the perspective of a traditional discipline alone.

The design of large-scale engineered systems has demonstrated that mono-disciplinary, inter, or multidisciplinary approaches do not provide an environment that promotes the collaboration and synthesis necessary to extend them beyond existing disciplinary boundaries and to design truly creative and innovative broad solutions to these problems [4]. They require not only the design of engineering systems with numerous components and subsystems interacting in multiple and intricate ways, but they also involve the design, redesign, and interaction of social, political, administrative, commercial, biological, and medical, ... Moreover, these systems are prone to a dynamic and adaptive nature, so solutions to unstructured problems require the realization of activities that transcend the boundaries of traditional disciplines, i.e., transdisciplinary research and education are required.

This type of education and research emphasizes teamwork because it brings together researchers from diverse disciplines, and the development and sharing of concepts, methodologies, processes, and tools to create stimulating and fresh ideas that push the boundaries of solution possibilities. The transdisciplinary approach generates in people a desire to seek collaboration outside the boundaries of their professional expertise to make discoveries, explore different perspectives, express and exchange ideas, and acquire new knowledge.

2. FRAME OF REFERENCE

The first universities were structured around four faculties: Medicine, Philosophy, Theology, and Law, as areas that contained the *totality* of knowledge. The academics of the time were versatile and erudite, legitimate precursors of the thinkers and creators of the Renaissance [5]. With time these faculties became more and more specialized, and thus disciplines and sub-disciplines emerged and multiplied, to the point that, by the 1950s, there were more than 1,100 recognized scientific disciplines, not including the Humanities [5]. The association between disciplines, departments, and institutes is a relatively modern phenomenon and began to consolidate at the end of the 19th century. This departmentalization was important for maintaining disciplinary autonomies, obtaining funds for research, and consolidating academic prestige. In this way, professors and students develop and increase disciplinary legalities and often feel that theirs is the most important of all. But the 21st century is different and the problems are complex, accumulate, and demand immediate solutions. What follows is a description of the process that gives rise to the Transdisciplinarity with which today's problems must be addressed.

- *Disciplinarity* refers to a mono-discipline and represents a specialization in isolation. A person can study Biology and do well without any knowledge of Physics or Psychology. Moreover, if one were to write a list of sciences from left to right (Physics, Chemistry, Biology, Mathematics, Computational, ...) it is possible that they would be perceived as logically connected horizontally, not vertically. Mono-discipline is characterized by specialization, which is a method by which a scientific discipline gradually shrinks the margins of its object of study, away from the horizons of other specialties, so that each area becomes insignificant and unrelated to the rest, as a result of fragmentation and a reductionist approach. The reasons that advocate mono-disciplines are considered the most inefficient method to deal with a complex reality.

- In *Multidisciplinarity* a person studies, simultaneously or in sequence, more than one area of knowledge, but without making any connection between them. Thus he may, for example, be proficient in Chemistry, Sociology, and Linguistics, but without generating any cooperation between them. Multidisciplinary teams are common and frequent nowadays. In them, the members carry out analyses separately and from the perspective of their disciplines. Thus, the result is a series of reports stapled together, without any synthesis or integration. This happens, despite the convergence of members from different disciplines, because the multidisciplinary approach remains fragmented and reductionist, and because the autonomy of the participants is maintained: it is not necessary to share the same language and the same goal, just someone to classify and incorporate the results.

- *Pluridisciplinarity* implies cooperation between disciplines, although without coordination. It usually occurs between related areas of knowledge and on a common hierarchical level. An example is a combination of Physics, Chemistry, and Geology or History, Sociology, and Language. The study of each of them reinforces the understanding of the others.

- *Interdisciplinarity, on the* other hand, is organized in hierarchical levels and implies coordination from a higher to a lower level. In this sense, a purpose is introduced when the common axiomatics of a group of related disciplines are defined at the next higher hierarchical level. So what is meant by hierarchical level? The disciplines listed horizontally, plus others, can be considered as the second floor of a building, and identifiable as the empirical level. Immediately above, on the second floor, is another group of disciplines that constitute the pragmatic level and include, among others, Engineering, Architecture, Agriculture, and Medicine, ... The third floor is the normative level, which involves disciplines such as planning, politics, social systems design, and environmental design, ... Finally, the top floor of the building corresponds to the value level and is occupied by Ethics, Philosophy, and Theology. Thus a hierarchical picture is defined in which the purpose of each level is defined by the next higher one.

- *Transdisciplinarity, on the* other hand, is the result of coordination between all these hierarchical levels, which can now be represented differently. The disciplines at the base of the building describe the world as it is. Here one can learn from the physical laws of nature and the principles that drive life and societies. This level asks and answers the question of *what exists*. For example, Computer Science is about software development; Physics is about quanta; Chemistry is about the elements of the periodic table; Biology is about the composition of cells; and Mathematics is about problem-solving. The organizing language of this level is *logic*.

  The next level consists mainly of technological disciplines and asks and answers *what we can do* with what has been learned from the empirical level. Here we learn how to build airships, how to travel to planets, and how to navigate offshore. What this level does not say is whether to implement human capabilities, and the danger is that you often do things simply and only because you know how to do them. The organizing language of this level is *cybernetics*, which emphasizes only the mechanical properties of nature and society.

  The normative level asks and answers the question of *what we want to do*. In democratic societies, the answers would normally be submitted to a vote. An example is the control of environmental impact, which originates as a consequence of the environmental movement; and those that are achieved from other movements, such as the *indignados*. These and others are clear examples of people who can directly influence what they want to happen in their environment. The organizing language of this level is *planning*.

  The value level asks and answers *what we should do,* or better, *how we should do what we want to do.* This level goes beyond the present and immediacy. It points to generations to come, to the planet as a whole, and an economy as if people mattered. By making explicit a global concern for the human species and life in general, *organizational* language must be a kind of deep ecology. In any case, education systems are not thought of or structured in a transdisciplinary way. At best some interdisciplinary efforts are found, but the experiences are mainly marginal and not integrated into the macrostructure. Universities, departments, institutes, and faculties are still organized around isolated disciplines.

In summary, and looking back at the transdisciplinary building, it is easy to realize that most social actions do not go beyond the combinations between the lower levels. In behavioral terms, this edifice does not pass the test and as long as it is not restored, humanity will not be able to successfully face the great problems of this century. So how to do it? It is certainly not easy, but the first thing to think about is to radically modify the structure of education systems and academia, which in most cases seems impossible. Internal resistance can become insurmountable, since generally the dispute within which academic prestige is built, vigorously attacks any structural change in its discipline. It is quite surprising when one considers that almost three hundred years ago Leibnitz and Théodicée [6] expressed their hostility to universities because their organization in terms of faculties prevented the expansion of knowledge across and beyond disciplines. Change is necessary and despite all the existing difficulties, it can only come from within the system, and through action and cooperation among educated scholars. It is possible to detect here and there that such a process is already underway.

In general terms, transdisciplinarity means something different from interdisciplinarity, firstly, respect for the scientific status, and secondly, respect for the social function. In terms of scientific status, the concept of transdisciplinarity is not just a simple combination of existing disciplines, but a transgression of their traditional boundaries and thus a transformation of them into something new, where they will have their own identity as long as they have general terminology, which starts from the individual discipline itself. Transdisciplinarity is therefore expected to close several gaps: 1) between the two cultures of (natural) science and the social and human; 2) between specialists and generalists; and 3) between applied and basic research. This results from a process that starts from mono or multidisciplinarity and transcends interdisciplinarity to transdisciplinarity. Secondly, regarding the social function of science, the concept of a transdisciplinary does not adhere to the long-standing hypothesis that science should be in an ivory tower but rather implies a transgression from the scientific to the society that is affected by its results, and a transformation into a new science that is human-centered, democratic and participatory.

Society plays a very important role in this new perspective of scientific research and cooperation because transdisciplinary knowledge must be re-contextualized for a wider audience of multiple disciplines, where it becomes more accessible and interpretable [7]. For Kleiber [8], transdisciplinarity means pooling disciplinary knowledge and information, technological revolutions, and the creation of networks and new forms of knowledge. Due to the global aspect of today's problems, which cannot be solved by individual persons or groups, it is necessary to involve other sectors of society [9]. Moreover, since knowledge is transgressive, transdisciplinarity does not respect the imposing institutional boundaries [10].

Transdisciplinarity, therefore, crosses national borders because it is a transnational concept. Hence, it means more than a sum of researchers from different disciplines working together, as in multi- or interdisciplinarity. Another aspect is that it also crosses academic boundaries to solve real-world problems. Universities and other research organizations have to be open-minded and willing to cooperate with non-academics and scientists from other disciplines. In this understanding, they can learn from each other, because collaboration in transdisciplinary work requires horizon-opening actors and participants from science to contribute new views and ideas, with the aim of better understanding the real-world subject and testing and adapting their theories [9].

3. EPISTEMOLOGICAL CONSTRUCTION OF TRANSDISCIPLINARITY

The concept has been defined in various ways, for example, Gibbons and Nowotny [10] analyze it as a pragmatic vision focused on an approach to solving concrete problems. For Basarab Nicolescu [11, 12] and from the epistemological point of view, it refers to the things that all disciplines have in common, at the same time in the middle, across, and beyond. Its objective is the understanding of today's world, where one of the imperative needs is the unity of knowledge. It is a theory that places the human being at the center of its concerns, a vision with greater generality that is suitable for discussing issues in education, ethics, and practically any social aspect.

In this regard, it is interesting to note that Goethe, whose scientific contributions have been unjustly overshadowed because of his colossal achievements in literature and the arts, was disturbed by what he believed to be the limitations of Newtonian physics. For him, science is as much an inner path of spiritual development as it is labor aimed at accumulating knowledge of the physical world. Moreover, he asserts that it is not only a rigorous training of the faculties of observation and thought, but also of others that can tune into the spiritual dimension that underlies the physical, such as feelings, imagination, and intuition. Seen in this way science has as its supreme objective the excitement of the feeling of wonder through contemplative vision [13]. Heisenberg [14], one of the fathers of quantum physics, suggested that there is no conflict between the acceptance of Goethe's Way of contemplating nature and the contributions and discoveries of modern physics. For him, the two senses are complementary, rather than opposites.

According to Nicolescu [15], Transdisciplinarity is a relatively young approach. Jean Piaget developed the concept seven centuries after disciplinarity evolved. The word itself first appeared in France in 1972 in conversations between Piaget, Jantsch, and Lichnerowicz. Piaget [16] asserted that interdisciplinary relations should evolve to a higher, transdisciplinary stage, which would not merely recognize interactions or reciprocities between specialized investigations but would seek them within a total system and without stable boundaries between disciplines. Although this description is vague, it has the merit of pointing to a new space of knowledge: *without stable boundaries between disciplines*. However, the idea of a total system opens the possibility of a transformation of transdisciplinary into a super or hyper-discipline, a kind of science of sciences. Understood in this way, transdisciplinarity would only be a new (higher) phase of interdisciplinarity [17].

For his part, Erich Jantsch [18] falls into the *trap* of transdisciplinarity as hyper-disciplined and states that it is the coordination of all disciplines and interdisciplinary of the education system based on a general axiomatic approach. This places it within a disciplinary framework. However, its historical merit was to highlight the need to invent an axiomatic approach to it and to introduce values in this field of knowledge. Meanwhile, for André Lichnerowicz [19] transdisciplinarity is a transversal game to describe the homogeneity of theoretical activity in different sciences and techniques, regardless of the field where it takes place and, of course, this activity can be formulated only in mathematical language.

For him, it is precisely this non-ontological character that gives mathematics its power, its fidelity, and its polyvalence. Lichnerowicz's interest in transdisciplinarity was accidental, but his remarks about the non-ontological character of mathematics must be remembered. Another author who contributed to this initial process was Edgar Morin [20], who shortly after these authors began to use the word transdisciplinarity, and although he did not define it as such, for him it was, in that period, a kind of messenger of freedom of thought, an intermediary between disciplines.

In the decades that followed, the use of the term expanded and became linked to entire paradigms, such as systems, feminism, and Marxism; broad interdisciplinary fields, such as area studies and cultural studies; and synoptic disciplines, such as philosophy, geography, and religious studies. Likewise, a quick web search reveals a multitude of sites with this label in fields as varied as learning assessment, art education, mental health, rehabilitation, special education, engineering, economics, ecology, human population biology, computer science, knowledge organization, and team and collaborative work. On the other hand, international congresses and events are also organized around the subject, comprehensive journals are published and research centers are structured and developed. In short, transdisciplinarity is already an issue that attracts worldwide attention.

In the last decades of the twentieth century, two currents around transdisciplinarity gained wide attention. On the one hand, Basarab Nicolescu [11], advocates a new type of transdisciplinarity and begins to develop a broad scientific and cultural approach, to facilitate long-term dialogue between specialists who share a new worldview of complexity in science. In contrast to the one-dimensional reality of classical thinking, transdisciplinarity recognizes multidimensionality. This vision, which replaces reductionism with a new principle of relativity, is transcultural and transnational, embracing ethics, spirituality, and creativity. It is not a new discipline or super disciplined, and Nicolescu calls it *the science and art of discovering bridges between different areas of knowledge and different beings*. The main task is to elaborate a new language, and logic, and to structure the concepts to allow a true dialogue.

The other project, fundamental to the case studies around transdisciplinarity, is a research-oriented and problem-solving approach, which emphasizes the convergence of transdisciplinarity, complexity, and cross-sectoral in a unique set of problems that do not emanate from within science [21]. This current affirms that societal problems are increasingly complex and interdependent, therefore, they are not isolated to particular sectors or disciplines and are not predictable. They are emerging phenomena with non-linear dynamics, uncertainties, and high political stakes in decision-making [22], which focus on complex and heterogeneous domains where the need for transdisciplinarity is ubiquitous.

They are invoked in fields such as human interaction with natural systems (agriculture, forestry, industry, and megacities), and major technical developments (nuclear, biotechnological, and genetic). It has also demonstrated effectiveness in fields where social, technical, and economic developments interact with elements of value and culture, such as population age, energy, health, nutrition, sustainable development, landscape, housing and architecture, and land and urban waste management [23]. Each of these issues is multidimensional and in the past, they were structured according to their disciplinary and sectoral boundaries. This transdisciplinary approach has highlighted the limits of segmented problem-solving thinking.

According to Nicolescu [11], epistemologically, transdisciplinarity is based on three fundamental pillars: 1) the levels of reality, 2) the principle of the included third party, and 3) complexity. Furthermore, it recognizes the rational and the relational as simultaneous modes of reasoning. Therefore, transdisciplinarity represents a clear challenge to the binary and linear logic of the Aristotelian tradition. In the course of human evolution the transition from oral communication, where knowledge is imparted through stories and myths, to written communication (essentially the Western product of the development of the Phoenician/Greek alphabet), the primacy of rational thinking over relational thinking became the rule. The result has been that the fascination produced by reason has been so great that other faculties and feelings that facilitated, as it were, the understanding of nature from within have been lost.

For a pragmatic understanding of the different modes of thought, it is necessary to examine the pillars of Nicolescu's transdisciplinarity [11]. In adopting the first pillar of his proposal, the *levels of reality*, he designates as the reality that resists experiences, representations, descriptions, images, or mathematical formalizations. Quantum physics made it possible to discover that abstraction is not only an intermediary between man and nature, or a tool to describe reality, but rather one of the constitutive parts of nature. In quantum physics, mathematical formalization is inseparable from experience [24].

The coexistence of both worlds, as revealed by science so far, coincides with many similar visions that emerge from some religions, traditions, and beliefs, when it comes to searching deeper into the inner universe. Despite everything, it must be realized that, although transdisciplinary research and approaches are necessary, transdisciplinarity itself remains an unfinished project, around which there is still much to be discovered and investigated. It should be clear that at this stage it is as much a tool as a project.

The second pillar of transdisciplinarity is the axiom of the *included third party*. Nicolescu [25] recalls that history will credit Lupesco [26] for having shown that the logic of the included third party is a true, formalizable, formalized, multivalent, and non-contradictory logic. The logic of the included third party is not a metaphor, but, in fact, a logic of transdisciplinarity and complexity, since it allows, through an iterative process, to cross the different areas of knowledge coherently and to generate a new simplicity (or *simplexity*, according to Nicolescu). This does not exclude the logic of the excluded third party, it only limits its boundaries and range of influence, besides, both logic are complementary.

Beyond the verification of the existence of different levels of reality, the last century witnessed the emergence of many areas of *complexity* science (the third pillar of transdisciplinarity), chaos theory, and nonlinear processes. Systemic views resulted in the disappearance of assumptions that nature can be described, analyzed, and controlled in simple terms that correlate with traditional linear logic. However, when it comes to disciplines related to the social, the economic, and the political no significant breakthrough is found.

Paradoxically, the concept of a one-dimensional reality, oriented by a logic of linear simplicity, appears in them as strong as ever, precisely at a time when society must adapt to a world undergoing ever more accelerated changes.

On the other hand, the relationship between a complex world and nature requires complex thinking, and Edgar Morin's proposals are oriented in this direction. Among other things, this author proposes a radical reformulation of the organization of knowledge, taking into account its growing complexity. The idea is to develop a type of recursive thinking, that is, one capable of establishing feedback loops in terms of concepts such as whole/part, order/disorder, observer/observed, and system/ecosystem, in such a way that they remain simultaneously complementary and antagonistic [27].

At first glance, Morin's proposal seems to be an impossible task. However, once it is understood and integrated into a new way of looking at the world at the different levels of reality and the associated logic of the included third party, the vision and the way to proceed become clearer. The underlying principle is not to separate the opposites of the many di-polar relationships that characterize the behavior of nature and social life. Such a separation, normal in rational thought and its corresponding linear logic, is, in reality, artificial, since neither nature nor human society functions in terms of mono-polar relations. The insistence on artificially and ingeniously simplifying knowledge about nature and human relations is the force behind the growing dysfunctions that are provoked between the systemic interrelationships of both ecosystems and the social fabric.

Morin's research is not limited by disciplinary boundaries, because it is transdisciplinary and draws on a wide range of what he calls *relevant knowledge* [28]. In other words, he does not approach his topics from what others have called a *disciplinary-driven perspective* [29], meaning that he is not driven by problem-solving in the context of a specific discipline's agenda. Rather, its research is driven by thematic demand and moves across disciplines to draw on knowledge that is relevant to shed light on it. This is fundamental and makes Morin's vision of transdisciplinarity so important and timely, because it is not grounded in attempts to create theoretical frameworks of abstract totalization, nor is it oriented to promote the agenda of a mono-discipline. It is based on the need to find the knowledge that is relevant to the human quest to understand and make sense of life, and to answer the big questions that are increasingly left out of the academic discourse, precisely because they are too complex and because they cut across a variety of disciplines.

Morin's approach has always been both planetary and personal, and in his holographic method, he addresses key political issues through a combination of theoretical and historical reflection on the state of a grounded world, with ample examples of reflections and experiences. In addition, he manifests his willingness to wrestle with deep existential questions that are often erased in the often sterile discourse of the social and philosophical. Morin characterizes his later work on Complex Thought as an attempt to develop a method that does not mutilate, that does not fragment, or abstract, that does not do violence to life, and that is not one-dimensional, anemic, antiseptic, or homogenized. This transdisciplinary approach is reflected in the arguments he brings together with Lefort and Castoriadis [30].

Thus, transdisciplinarity derives its notion of complexity from new sciences, such as quantum physics, chaos theory, and Complex Adaptive Systems. From this perspective, there is a difference between a complicated and a complex situation [31]. A wicked problem is difficult to solve because it is complex and detailed. In a complex problem, an additional characteristic appears the process of derivation of some new and coherent structures, with particular patterns and properties, which emerge as a result of the network of relationships between people. What makes solving a wicked problem special is that this set of relationships is constantly adapting and is at the heart of the problem. In addition, any information pooled will be modified as it is passed from one person to another within those changing relationships. Energy and information are constantly being formed, which means that the fertile space between disciplines is constantly changing. Therefore, not only does the space change, but also the people, their relationships, the nature of the information shared, and the energy flows. Because no one can operate without being a part of the whole, no one can control the space [32].

If one accepts that reality is a coherent whole comprising several layers, then one must agree that one must constantly be aware of all of them without looking at anyone in particular. This awareness means that one does not only look at an individual aspect of a complex problem but directs attention to the whole that makes it up, such as the layer of invisible particles, the material, the biological-ecological, the social, the psychological, the economic, the political and the technological, so the challenge is not to lose sight of the whole. From this perspective, it is easy to see why transdisciplinarity is so necessary and important for solving problems in today's world. A solid intellectual outer space would consist of a collection of different disciplines that have nevertheless found a way to live and work together to create integrative and embedded knowledge [33].

To gain a deeper understanding of the world (the hallmark of the transdisciplinary approach) one must pass through a broader understanding of these different realities (rather than images) and their complexity [11]. This understanding can evolve if the space in which it operates is nurturing and open to various realities [34]. Nicolescu [35] explains that this concept refers to the zone of non-resistance to perceptions, a place where the concept of reality can stretch beyond known experiences. Here one must try to set aside the limits of rationality to cross through the veil of the real. Imagine the doors that would open if one assumes that there are simultaneous and independent realities that manifest themselves through interactions with them. Human beings will never stop questioning and seeking broad solutions to the pressing problems of the world, so imagine the depth of understanding of the world that would be achieved by embracing this way of thinking, even when the results are contrary to what common sense suggests [36].

In this state of mind, it would be possible to see that information comes from outside the self and is transformed by it. As one moves through the veil to other realities the flow of consciousness corresponds to that of information from others in a fertile space. It is necessary to move from seeing things as dualities to seeing them as open, more complex units. If the quantum world is taken into account in the way of thinking, it could be said that problem-solving is associated with a substance-energy-information-space-time complex [35]. There is nothing simple about this because it is transdisciplinary, but gaining a deeper understanding of the world is not a simple thing either.

In this respect and through the knowledge of complexity, Edgar Morin [37] calls for a new dialogue that unites humanistic and scientific cultures. Unfortunately, most of the existing transdisciplinary research takes place only across hard disciplinary boundaries, such as physics and chemistry. Even when real integration into the social occurs, it is often accompanied by a tendency to concepts and approaches that are incompatible with, and sideline, hard knowledge. Therefore, scientific efforts play an important role, but they are framed in a dynamic and self-referential process of solving and creating social and ecological problems at different scales of space and time [38]. Education is vital to the future of these perspectives, which is why Morin [37] calls for education systems to take a transdisciplinary approach across primary, secondary, and higher education levels, but never separately.

4. CONCLUSIONS

Transdisciplinarity by itself consists of a practical way of approaching problems systemically, but it is an unfinished project that requires many systematization efforts that still need to be carried out. The disciplinary refers to only one level of reality, while the transdisciplinary extends its action across several of them. Discipline and transdisciplinary should be understood as complementary, but the transition from one to the other is achieved through a journey through the different levels of reality, generating reciprocal enrichment that can facilitate the understanding of complexity.

Transdisciplinarity, rather than a new discipline or super-discipline, is a different way of looking at the world, more systemic and holistic. While the epistemology of transdisciplinarity may be relatively clear, its applicability as a methodology in the sciences and engineering still suffers from shortcomings. In particular, greater clarity needs to be achieved concerning the levels of reality in the world: Do knowledge and understanding belong to different levels of reality? What about being and having reason or intuition? Do anthropocentric and bio-centric worldviews and attitudes belong to different levels of reality? Can it be argued, for example, that development and environment, often identified as opposites in conventional economics, are opposites only at the anthropocentric level and that this opposition is resolved from the bio-centric level?

All these questions are open, however, they hint at the way forward in a system, such as education, whose objective is to complete and consolidate transdisciplinarity as a project aimed at improving the understanding of the world and nature. It is clear that if this effort is not carried out, greater and greater damage to society and nature will continue to be generated because the visions and assumptions of understanding and action are partial, fragmented, and limited. The challenge is to practice transdisciplinarity systematically, but according to possibilities, and to make efforts to perfect it as a worldview.

Since universities have not yet been identified that are fully oriented to train their students in a transdisciplinary manner, it is imperative to create instances that stimulate their application and development. It is urgent to think of a new education system and to transform the Industrial Age's objective of *educating* by *competencies*. Today we need an Education and Training System that thinks transdisciplinary, that forms people and trains professionals, and whose objective is to achieve these goals through horizontal and vertical achievement in the curricula. But designed from multidimensional and transdisciplinary integrative projects.

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X

Challenges and opportunities of Virtual Reality principles in social relationships and Information Technologies

Virtual Reality VR is a technological development that in a short time has become an area of wide influence in the way people communicate, influencing on many occasions the way they relate socially. This chapter presents the results of an investigation to find and analyze the principles on which VR is structured and, based on a review of the literature and the authors' experience, it is documented and analyzed while discussing its influence on social relationships. The development examines its usefulness in other areas and its effects on people's lives, presenting different points of view that, in many cases, do not have scientific support, but are worth considering given the level of penetration that this development has achieved in society. The conclusion is that there are several uses for VR besides entertainment, such as engineering, simulation, research, and recovery of patients after accidents, among others. But there is still the question of its effects on the brain, in the sense of leading people to want to live in a *virtual reality* that offers them what they cannot find in *real reality*; as well as in their *social relationships*, because it takes them away from real reality to a virtual reality where they can assume the representation of their preference.

1. INTRODUCTION

In April 1993, the National Center for Supercomputing Applications NCSA made public the development of the Mosaic web browser and, since then, people have been navigating the digital ocean of the web. Subsequently, the rapid expansion of the Internet and the massification of tools to use it gave it a level of importance and made it an inevitable component of social life, the impact of which is invaluable today [1]. As a technological development, it permeates all ordinary activities and its influence is such that the advances and innovations, which are added to it daily, seem integrated into the everyday life of this society.

In addition, information on the web is, in a way, open and can be accessed and shared across borders, religions, cultures, and ideologies; in business, it does not move up and down because it has a social life of its own and it has a social life of its own and moves according to people's needs for interaction [2], whether to be informed or to make better-informed decisions, to better understand a particular situation, to learn about a topic that catches their attention, or to obtain some kind of economic, social or cultural benefit; and the various dimensions in which society develops are nourished by it to make both trivial and transcendental decisions.

All this has led humanity to live amid an accelerated socio-technological co-evolution in which information has become money that people carry, with which they interact through transfer and give it added value through perception. In this new context, the evolution of the Internet itself becomes an asset of the ecosystem, in which humanity satisfies its collective and individual need to learn and grow. Moreover, as an evolutionary process, it is natural to imagine that the technologies for visualization and presentation of this information, for example, 3D virtuality, will be increasingly integrated into it, to the point that it is possible to perceive the social, professional, educational and commercial consequences that are beginning to take shape on a large scale in the so-called Virtual Reality.

A domain then emerges in which communication, collaboration, and work converge, in a kind of revolution that aims to transform the web into an increasingly important medium for communication, learning, research, collaboration, entertainment, and industrial development, as shown in Figure 1, and which materializes in a revolutionary context that provides opportunities for technological, commercial, cultural, scientific and educational development and that, in a certain way, can help improve the quality of life of the Information Society.

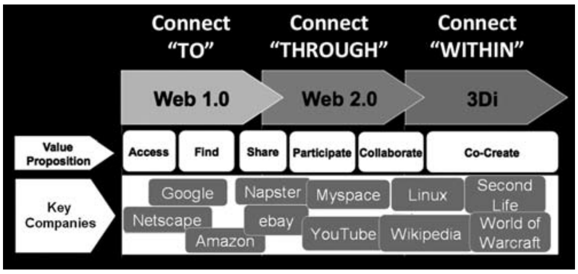

Figure 1. The Three Webvolution Waves [3]

One manifestation of these changes is observed in the fact that the web is migrating from a two-dimensional to a three-dimensional navigation interface and, in the same way, that Mosaic impacted different social environments, this move from a static-bi-dimensional to a virtual-three-dimensional environment for managing information is originating a new and significant revolution [4]. The emerging scenarios enable, among other things, collaborative work between people from different parts of the world and in 3D environments in diverse areas. Currently, this revolution is evident in the innovation of different employment patterns, generating worlds in which people participate and contribute without physical presence [5], while virtual economic markets emerge in which real products are traded [6].

As the revolution progresses, new scenarios become a reality, immersion takes hold as an omnipresent environment, new ways of creating and innovating are generated, business and learning opportunities appear, vehicles for knowledge generation and development are created, and borders, cultures, and distances vanish, generating universes such as the one shown in Figure 2.

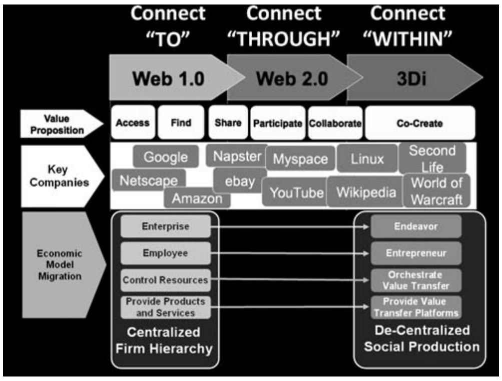

Figure 2. The Webvolution Encourages Social Production [3]

But not all scientists, researchers, and ordinary people agree that this revolution will bring only benefits and goodness to humanity, and, although they do not deny the advantages and potential of VR, they have misgivings about its effects on individuals and social conglomerates. Some of the works analyzed in this research speak, for example, of *health problems*, from the physical, physiological, and psychological [7, 8]; from the security to the privacy of people and nations [9]; social problems generated by an experience of isolation in terms of family and social coexistence [10]; can lead to inhibition of personality development [11]; puts intellectual property and physical safety at risk, while potentially increasing the sense of triumph [12]; or what about the issue of insurers and claims response? [13].

These and other points of view originated the research whose results are presented in this chapter and whose objective is to establish the principles of Virtual Reality, to analyze its benefits and problems from its integration into other research areas. In addition, an analysis of key concepts such as real reality, virtual reality, and realism that support the description of the principles and the discussion about its transdisciplinary relationship with other areas is presented.

2. THEORETICAL FRAMEWORK

2.1 Virtual Reality

Throughout history, the development of cultures has been marked by the need to capture, transmit, and experience ideas, and for many, the most recent proposal in this timeline is Virtual Reality. Historical records range from paintings, and narratives to share stories and experiences, printing, radio, and television waves, to digitalization, and VR is the technological development that responds to social needs to find practical and effective applications to carry out communication. Because of this and taking advantage of advances in Computer Science, Virtual Reality is a real-time graphical simulation technology that allows people to experience immersion in a reality that is not their natural environment [14].

The idea of an immersive experience began in 1952 when Morton Heilig created the first Head Mounted Display HMD, a 1 to 4-person simulator that provided the illusion of reality using a 3D picture with smell, stereo sound, seat vibrations, and wind. In 1987 Jaron Lanier, founder of Visual Programming Lab, coined the term *Virtual Reality* and became one of the first companies to sell VR equipment such as data gloves and glasses. In 2012 Palmer Luckey created a portable HMD, which he called Oculus Rift, much more comfortable than previous models and with more robust software, allowing the user to be truly immersed in the game.

Due to these technological advances, society has migrated many of its activities to digital places, to the point that new generations are increasingly moving away from physical interrelationships to choose network immersion. All these activities are mediated by multiple technologies, such as telephony, video, messaging, blogs, social networks, games, online universes, forums, and chat channels [15] ... which, together, make up a kind of complex ecology in that they have virtual experiences [16, 17]. In addition, the social penetration of these communication technologies allows people to potentialize the use of information to plot and achieve goals that with previous developments would not have been possible [18].

One of the particularities of the reception of virtual universes is that, although computers and software are considered to be cultural products of the real world and therefore subject to the rules and norms of the real world when entering them all that disappears. The reason is that very different rules must be respected in them, in most cases established by the users themselves, which generates phenomena hitherto invisible and considered discontinuous with culture.

In any case, the global world is more interconnected through digital technologies and this structure is evolving at an accelerated pace, in part because it works in direction and iteration, that is, it learns from past successes and failures to achieve new and better products, over and over again. Currently, a convergence of four technological initiatives is envisioned toward a singularity that could define the next social communication structure, which some have named *Immernet* or Immersive Internet [19, 20]. This development will enable information dissemination and communications for and between inhabitants of virtual worlds while generating new commerce strategies and facilitating structures, but requiring new forms of learning and interaction. Kapp and O'Driscoll [3] represent this *singularity* in the form shown in Figure 3.

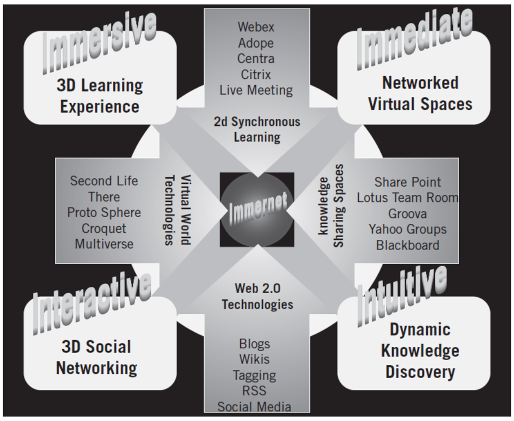

Figure 3. The Immernet Singularity [3]

For the authors, this revolution will bring communication between people into a kind of third dimension, in which they will be able to establish dialogues and share data through immersive experiences. This new component of the communication equation will raise the quality of interactions between people anywhere in the world because they will do so in real-time and by selecting the contacts that are of real interest to them. The point is that no one will work for the structure, but rather *Immernet* will work for them, offering job opportunities and the choice of whom to work with, because, as a non-linear ecosystem, it departs from formal structures.

2.2 Real Reality and Virtual Reality

To define the real is to speak of what exists and how it is perceived, while the virtual is something imagined or modeled from the real. Philosophically, the real includes that which has existed, exists, or will exist and the virtual are things that can be imagined, but not really. On the other hand, real reality refers to the real world, and virtual reality to the modeled world, and the former seeks to differentiate the experiences, interactions, and activities typical of the real world from the sensations of the virtual domain.

This differentiation is necessary because digital development has extended the dimensions of the material universe, i.e. time, space, and matter [21], the effect of which can be seen in innovations that change the material to non-material by developing more and more digital products and services, in companies that occupy virtual spaces instead of real spaces and in processes that are not performed in time but *non-time*. After all, they are not executed in a linear sequence of real events but programmed autonomous events.

The opportunities, interactions, and communications in both realities imply that society is moving from the reality of time, space, and matter to the virtuality of no-time, no-space, and no-matter [22]. But, although these new dimensions are located outside of any time and place in the world, the consensus is that, for the moment, the most rewarding experiences are those that are located in real reality. Then, finding an answer to what reality is is not easy, because to accept that it is everything that is perceived through the senses would be to ignore entities that cannot be perceived but are real. For Westerhoff [23] reality is everything that, although it is not thought, believed, or felt, does not disappear; his definition does not consider real objects such as stock exchanges that, if one stops believing in them, would cease to exist.

On the other hand, some try to define it in different ways: 1) through the comparison with a planet without human beings in which everything that would be real with them is not, such as countries, wars, and languages, ... [24], or 2) by confronting it with fundamentalisms, i.e. that it is constituted by all fundamental things that, to exist, do not depend on others [25]. Now, this definition is more restrictive than that of the world without humans, because realities such as a mountain would not be a reality because their existence depends on other things.

From the scientific point of view, real reality can be defined only in terms of matter and energy, that is, in an optic in which anything is real. From this practicality, science needs a few arguments to explain reality: particles, forces, quantum mechanics, etc., and although it seems a consistent definition for real reality it still seems somewhat insubstantial because even the most solid matter is constituted of atoms made up of subatomic particles and electrons. This means that this matter is mostly empty spaces because among its components there is nothing at all. According to physics what makes matter real, with shape and volume, are the electrons that give it shape, i.e., electrons, quarks, and gluons make up most of the real stuff [26]. But when matter and dark energy are included this standard model loses clarity, because together they constitute about 96% of the real universe.

On the other hand, when CERN scientists observed the traces of something that seemed to be a particle predicted by mathematics more than half a century ago, a definition emerged in which real objects might not be made up of particles or strings, but of numbers, because mathematics is reality [24]. The issue here is to find out what mathematics is made of, because if its structures are derived from the empty set, i.e., nothingness, then all reality reduces to nothingness [27]. Moreover, mathematical structures do not need an explanation because they are located in a universe made of nothing and, therefore, for an object to be real it must not have existed in space-time. That is, mathematics does not require a physical origin because it can neither be created nor destroyed.

A more radical definition holds that, no matter what is accepted as real reality, it is probably wrong because the universe is a machine and everything in it can be explained in terms of information processing [28]. If conceptually one thinks of a computer as a machine that processes information and if this concept is combined with the fact that quantum physics is almost couched in terms of information processing, then one can conclude that such processing is the root of everything [29]. This assessment may not be so far off the mark because every process in the universe boils down to interactions between particles by tossing binary digits or bits that result in a continuous interaction of their atoms, i.e., reality. A striking feature of this definition is that it may shed light on the question of whether something other than nothingness exists, which would indicate that the universe really could have arisen spontaneously.

Any attempt to delve deeper into any of these definitions will always generate difficulties and conflicting positions, so taking sides with any of them may result in a distancing from reality itself. Then Virtual Reality arose as a technological concept in which it is possible to find more common ideas, which takes many of these approaches to structure a definition of reality and which is based on the conception that the universe is fundamentally composed of information. This concept is supported by discoveries such as that space-time is pixelated [30], so it would be a holographic representation where 3D reality is a projection of information encoded on the two-dimensional surface of the boundary of the universe (http://www.quantumgravityresearch.org/). On the other hand, according to Hegel, the essence of technology appears only in concrete and particular technologies that necessarily embody the essence of technology [31]. In other words, every element of the real world is created with the help of technology, so human beings are technological products because the only way to create them is through technology.

It is therefore not unusual for definitions of Virtual Reality to be presented in technological terms, although it is also not unusual for there still to be no consensus [32]. First, because the most important characteristic for identifying VR is whether or not it has technological components, a definition that does not provide a clear conceptual unit of analysis for it. Secondly, because it has no theoretical dimensions that allow it to vary, i.e., the definition assumes VR all systems that include technology and non-VR those that do not. However, this statement is ambiguous because it does not determine the theoretical criteria that allow comparisons to be made.

Even so, popular definitions always refer to some technological concept, for example, that it is a technology that persuades the user to be in a world different from the real one because it replaces his or her sensations with data generated in a computer with factors such as immersion, interactivity, and intensive information [33]. In this definition, there is a feeling that VR is a relatively new development. It is linked to computers, which is not true because it has been part, in various ways, of the development of cultures. For Sherman and Craig [34] it is a world in which interactive simulations give the user the feeling of being immersed in it because the actions generate stimuli to their senses. This may provide more insight into the essence of VR, but first, the term *user* should be interpreted because if it is considered to be a person, then what about avatars? Assuming this interpretation excludes many types of virtuality it is more suitable for understanding state-of-the-art Virtual Reality.

Stanovsky [35] states that they are interactive computer-generated simulations that, among other things, can be shared, immersive, and global. There are gaps in this definition because if simulations and interactivity are necessary for VR, then how do simulate real reality, how do differentiate that simulation from those generated by other media, and what makes human-computer interactivity so special? Another definition holds that it is an interactive, computer-generated 3D world with a personal perspective that does not require total immersion. Here it is observed that personal perspective is valued more than immersion because the latter is still considered to be in development and therefore could not be a necessary feature. Somewhat, or very, far from these concepts other authors claim that there cannot be a clear distinction between Real Reality and Virtual Reality, because with consciousness they are the same [36]. For them before the universe as it is known today there was no conscious mind and, when it appeared, it gave it the status of real. However, some detractors consider that one should not speak of something that cannot yet be clearly defined, i.e., consciousness.

2.3 Level of realism

Realism in VR depends substantially on the requirements of use, but in any circumstance, it should recreate as closely as possible the real world to be virtualized because the user's behavior and expected results depend on the level of realism offered. After all, objects in virtual environments are not real, but imitations or simulations that do not possess the characteristics that make them physical: weight, mass, location in space, and physical and chemical capabilities. Moreover, some types of virtual objects, actions, and events can qualify as real because they are not only simulations, but they come to reproduce ontologically what they imitate: light, sound, and structures such as images and melodies. On the other hand, they can reproduce institutional objects and actions: money, force, and actions such as selling and promising.

Likewise, there are virtual actions that often generate extra-virtual (physical) as well as intra-virtual effects, then they could be qualified as real actions, so virtual worlds must convince the user of the reality he is experiencing and, depending on the objective of the system, place it in a specific level of reality [21]. In this sense, the problem is that when modeling the real thing the result is always a crisp virtual representation, while real objects are rarely neat and usually have stains, dust, and scratches due to everyday use. For various reasons, this is not taken into account when modeling it and then the user's perception does not achieve an adequate level of reality. The issue is that validating the realism of a model is a complicated matter because people develop particular perceptions of each real environment, and if for someone the model is adequate it may not be for another, which prevents achieving a measure of perceptual equivalence [37].

On the other hand, the real world is multi-sensory, that is, people perceive it simultaneously through all their senses and this interaction generates a level of detail that goes unnoticed due to other dominant sensory inputs. That is why a virtual world must recreate that perceptual response and make the user believe that he is really in the represented scene, which must necessarily include the necessary sensory details because if it does not achieve it, it loses its level of reality and the user will not have the means of communication he requires [38]. For example, although touch is frequently used in virtual models the same does not happen with smell and taste, causing the richness that both add to the real world to be lost in the virtual world when humans generate taste by combining them. This measure of fidelity between the real world and the virtual world is known as the *level of realism* and is intended to be multi-sensory because the human being must virtually recreate the intimate perception with which he or she lives [22]. Therefore, to achieve the goal of a real-world experience in the virtual world, the user must receive an appropriate level of sensory stimulation for each sense.

3. METHOD

A systematic literature review was performed following the procedure proposed by Serna [39]:

1. *Select the review topic*: Principles of Virtual Reality.
2. *Define the research question(s)*: 1) What are the principles on which Virtual Reality is based? 2) How do they influence the lifestyle and quality of life of people outside of virtual worlds?
3. *Design the search strategy*: We search digital databases and the websites of companies and researchers working with Virtual Reality, using combinations of search terms in English and Spanish.
4. *Search criteria*: (virtual reality + social relations + principles + advantages + disadvantages + advantages + disadvantages + integration + usefulness)
5. *Databases*: ACM, IEEE, Scopus, Wos.
6. *Determine the inclusion and exclusion criteria*: 1) clearly describes and analyzes the principles of Virtual Reality, 2) are easily verifiable as principles, 3) can be evidenced in some application, and 4) descriptions are detailed and substantiated.
7. *Define the quality assessment*: the author or company evidence experience related to research or production related to Virtual Reality; level of dissemination evidenced in citations, comments, or recommendations; degree of acceptance or criticism; timeliness.
8. *Structuring the data record*: APA style.
9. *Define the data analysis*: the team analyzes groups of ten papers, first individually and then in argued joint discussions; only papers that obtain the approval of all the researchers are selected; only principles that meet all the inclusion criteria are included; then a joint analysis is carried out for the presentation of the report.
10. *To specify the presentation of the report*: the structure of Table 1 is defined to present the analysis report to the selected papers.

Table 1. Structure for the presentation of the report

Year	Title	Author	Principles	Argumentation	Analysis

4. RESULTS AND DISCUSSION

Since Virtual Reality is a recent technological development, its definition and principles are constantly being discussed and updated. In the previous content, an analysis of the most generalized definitions was presented, followed by a description of the VR principles found in the literature review and some that are associated with this area based on the authors' experience.

4.1 Virtuality

This principle refers to an aspect of reality that is ideal and real, therefore, it is the content of a given medium that can exist only in the mind of the author, or that can be shared with others. For example, the world represented by a film script exists only for the writer, but when the film is made, it becomes the real aspect of that virtuality. In addition, when technological developments are used to simulate a series of objects from a structure that its creator imagines, the result is a virtual world of the same. For Marín [40] it is an anthropological structure that is part of the experience and, therefore, it is not independent of the mind nor can it be reduced to something physical.

For Sherman and Craig [34] virtuality is a medium that presents a wide utility for the exploration and communication of ideas, supported by other means of human communication with which it shares properties. For these authors the term medium, as something that relates two things, can mean: 1) carrier, when it transfers matter and energy, and 2) communication when it does so with ideas or concepts. In any case, at the limits of each, there will always be an access point traditionally known as an *interface*, through which one can access virtual worlds that may be contained in media such as the human brain. In the real world, the sender communicates contents that allow the receiver to experience the physical part of them through Virtual Reality, that is to say, he interprets them in the brain and immediately creates the virtual world in which he can represent them.

This world is a simulated representation of an abstract domain in the mind of the creator that materializes by respecting rules of behavior (programmed or imagined, simple or complex) that can be automated, for example, in a computer program or through rules in a family game. Because this domain is an extension of the real world, it involves participants, objects, and rules established in the mind of the subject experiencing the immersion. Therefore, an important aspect of the principle of virtuality is that the person must have the capacity for wonder and belief in what he or she experiences. In any case and as a medium, virtuality allows people to communicate through mechanisms (virtual worlds) that support the transfer of content.

Although this communication exercise seems simple, it is the basis on which much of humanity's progress and culture is based, and this inclination to reflect and transmit ideas has always accompanied cultures, and technology is currently the means to achieve this efficiently. As part of this development in virtuality, the process begins when the person abstracts the real world and structures the communication in a virtual one, which turns it into a unique tool that offers special characteristics that other media do not possess, such as manipulation of time and space, interactivity, simultaneity, and dynamism, necessary to achieve the objective of the message.

4.2 Modeling and Simulation

The models represent the construction and operation of a system and although it is a simpler abstraction of it, its purpose is to approach the prediction of effects by changes or interventions. Therefore, it should be a representation as close as possible to the real system, but not so complex as to make it impossible to understand, i.e., it should offer a balance between realism and simplicity. In any case, these representations need validation processes known as simulations, in which known inputs are used and then the outputs are compared with those expected in the real system. All this is necessary because people must solve complicated and complex problems that cannot be constructed directly without first knowing their approximate behavior [41]. They then use the principle of simplification, i.e., subdivide the problem into simpler parts so that after understanding each one they can then understand the system as a whole.

As a stand-alone property and when properly understood and used, simulation is a powerful tool in many real-world contexts. It is a process in which a model of a domain is designed and then simulated using a means to conduct experiments, to analyze the behavior of the system in a virtual world before materializing it and putting it into operation in the real world [42]. In other words, the model represents the system itself, while the simulation represents its operation over time, seeking the eventual real effects of alternative conditions on the model's operation to select courses of action. Another objective of the simulation is control over the system because it is not feasible to acquire it due to costs, hazards, time, or simply because it does not exist.

In any case, the success of the simulation lies in the reliability of the data and information collected to build the model, as well as in the validity of the characteristics and behaviors because this determines its credibility. In the industry, the best way to verify and validate the models is continuously studied because the decision-making process to materialize them in the real world depends on it, therefore, the procedures and protocols must be oriented to satisfy the expectations as closely as possible to the expected performance. In any case, a simulation is a tool that can be used to evaluate the performance of a system, real or abstract, under different configurations and scenarios and during various periods.

4.3 Interactivity

Although it is a term that has not yet found a widely accepted definition in the literature, many are related to the measurement of specific dimensions, although some authors agree on certain operational properties. For example, as a descriptive characteristic of new media [43], or as feedback because the actors participate in message transactions [44], but, in any case, this communication flow must be linear or non-linear [45]. On the other hand, debate persists in the community about how to conceptualize or operationalize the term [46], although it is accepted that in everyday life it has to do with the capacity of a system to facilitate interpersonal communication.

In all the discrepancies around a definition for thermic, it is possible to find some basic common properties: it should be categorized as a relational variable; it resides in the minds of the actors as perceptions; it is manifested in the form, content, and structure of the technology; it is evident in the context of human-machine, or human-human communication through machines; it involves social presence, transparency, and ease of use; and it requires feedback, speed, and flexibility over time. In analyzing this scenario Kiousis [47] proposes a definition in which he assumes that it is the degree to which technology creates environments in which actors communicate, synchronously or asynchronously, and interact through a medium.

To this, we should add other key concepts that help determine the level of interactivity achieved by the actors in communication which, according to Chesebro and Bonsall [48], are: 1) proximity, related to the sensation of closeness that the actors perceive regardless of the distance that separates them; 2) sensory activation, operationalized through the use of the senses; 3) speed, perceived as the time lapses necessary to materialize the communication; and 4) operability of telepresence, related to the perceived credibility of the system. For these authors, the levels of interactivity vary according to the technology of the system, the configuration of the communication, and the perception of the actors.

Yacci [49] proposes additional attributes: 1) it is a cycle of messages that occurs between senders and receivers; 2) it occurs from the point of view of the receiver, who achieves the objective when a cycle of messages is completed; 3) it has two objectives: communication and learning, which will be achieved in that order by the sender and the receiver; and 4) coherent messages because otherwise the objective of communication will not be achieved. Liu and Shrum [50] state that interactivity is the level of communication achieved by the actors through a communication medium, combined with the degree to which the message influences them. They also add the concept of dimensionality (Figure 4), which in the process materializes from 1) active control, characterized by the voluntariness and instrumentalization provided by the actors; 2) two-way communication, a necessary skill for reciprocal communication; and 3) synchronization, because a lag in the process does not allow effective communication.

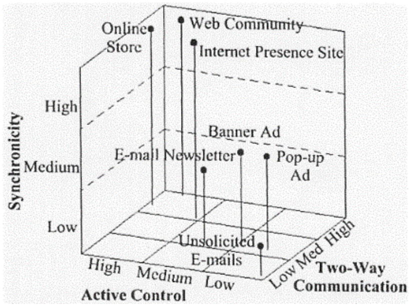

Figure 4. The three-dimensional concept of interactivity [50]

4.4 Immersion

This term refers to a state of the *self* in which the consciousness is immersed in an absorbing virtual environment that represents the simulation of *a* real *one.* In other words, it refers to an action in which the sensations of the real world are eliminated and replaced by their correspondents in the virtual world, taking advantage of the nature of the human senses to perceive in different ways the interactions in that context. To take advantage of the characteristics of the senses the interface of the virtual world must be wide, surrounding, vivid, and coincidental because the ultimate goal of immersion is to generate a feeling of presentiality in virtual reality. This notion is a combination of technological (immersion) and cognitive (perception) aspects that define a situation in which the brain and senses are directed to accept the virtual presence as real [51].

That is why some authors describe immersion as a participatory activity [52, 53] in which the brain becomes involved in the story until reality disappears and its presence in virtuality becomes concrete. From another perspective, it is conceived as a metaphorical term derived from the physical experience of being immersed in water, although one of the most important aspects of immersion is that it must replace the entire context, not just some components because otherwise, the brain would not achieve the sensation of presence in the virtual world. According to Gander [54], no greater immersion will be experienced by raising sensory perception, i.e., a video story does not produce more immersion than a text story. On the other hand, the level of participation of the actor does not increase the level of immersion because, for example, if he participates actively he will not experience more than if he does it passively. For this author, immersion is the same in any scenario, what changes is the capacity of the senses to take the brain away from the real world and involve it in the virtual one, because for him, immersion is a *mental absorption*.

On the other hand, in the field of Virtual Reality immersion is usually defined in terms of the technological dimensions involved and the level of interactivity applied, so it would be a technology-based characteristic [55]. Gander [54] describes the elements that an immersive experience should include: 1) *attention*: directed to the source (text, voice, images, sound); 2) *mental construction*: of the world, the plot, the temporal and causal connections between events, and other elements; and 3) *emotional state*: as a response to the content of the story. To these elements, we should add *active perception* from the point of view of predisposing the senses to perceive the virtual world.

Meanwhile, for González [56] immersion is a psychological process that the person enters when concentrating on the artificial world, but the process is complex and so far little studied. He proposes three factors necessary to achieve effective immersion: 1) *willingness to believe*: to accept the virtual world with the awareness that it is unreal, 2) *empathy*: to understand the feelings shared in the virtual world, and 3) *familiarity*: because the more one knows about this world, the less concentration is required. From the psychological point of view, we should add the *mental state* factor [57] because there is a risk of not being able (or not wanting) to leave the virtual world. In addition, there must be a trade-off between all of them because if the person has a greater tendency towards any one of them, then he or she will not achieve true immersion and, therefore, would not effectively enter the virtual world.

4.5 Sensoriality

In general terms, this principle is closely related to immersion because the greater the number of senses stimulated, the greater the degree of immersion. By combining the effects of both in the virtual world, the person achieves a disconnection of his senses from the real world, so he stops perceiving the environment and his senses tell the brain that his world is now the one presented by Virtual Reality. As a discipline, the purpose of sensoriality is to study and evaluate the normal and modified functions of the senses and feelings. This is useful because people live with diverse realities and need the senses to differentiate stimuli and capture the necessary emotions. Although it could be assured that everything that is felt should lead to correct reasoning, it turns out that most of the wrong ones originate in wrong perceptions.

As an area of research interest, it has had little attention and for a long time was considered an inheritance of the body-mind/senses-intellect dichotomy or a lower-order cognition. It took years before the senses were accepted as open doors to the real world and reality because they are a means of communication with the environment and their perception is the basis for constructing the world that surrounds each person [58]. The point is that what is perceived does not enter directly into what is learned, although it generates an automatic response from the brain indicating at the same time the type of learning that can be obtained. Based on this conception, Virtual Reality uses the principle of sensoriality to *deceive* the brain by telling it to learn as real what it is experiencing as virtual through the senses.

In other words, sensoriality is a characteristic that is captured by the senses through a receptive field that generates different types of stimuli, depending on the one the person uses, which is why it is also called sensory receptivity. In this sense, Virtual Reality adapts to the culture of the individual who wishes to be immersed in the virtual world, that is to say, culture and cultural stratum are fundamental characteristics to achieve sensory efficiency in the virtual world. For example, sensorially the virtual world is not the same for an African as for a European, because the senses of each one have different priorities and, therefore, they develop one more than the other. If this aspect is not taken into account in the design and development of the virtual world, it is possible that it will not reach the same level of effectiveness for both individuals.

4.6 Multidimensionality

The real world is defined only through dimensions and because of that it is described in terms of height, length, and width as characteristics to which the brain has become accustomed since mankind developed the senses. This is why the principle of multidimensionality is fundamental in Virtual Reality because worlds must accurately reflect real dimensions for the brain to assimilate its physical stay within something non-physical.

A dimension can be defined as an aspect or facet of something in terms of 1) characteristics, circumstances, or phases; 2) area, volume, or length; 3) symbolisms for space and size; 5) a physical magnitude, or 6) a technique for creating depth of visual information.

In Virtual Reality, multidimensionality is closely linked to the latter, and different techniques have been developed that allow, on the one hand, to creation of content from polygons, or stereoscopic to direct the brain to perceive them in several dimensions. In any case, virtual worlds must present a context close to reality, because otherwise, the brain perceives them only in two dimensions.

On the other hand, sensations must be added for the other senses because the real world is perceived by all of them. From this need, techniques and technologies such as 3D, surround sound and others have been developed to make the message to be communicated more real.

For Penrose [59], Morin [60], De Silva and Carlsson [61], and Giraldo [62], *multidimensionality* allows a total understanding of the world, real or virtual, because it helps to unravel the skein in which the message communicated by the sender is confused. Therefore, in this century with the emergence of interactive and multidimensional events and objects with random components, people have had to develop a strategy of thinking that is neither simplistic nor totalizing, but rather reflective to coexist with them, whether real or virtual.

In this process, they must build a relationship with all that this fabric implies to develop a univocal definition of the world and assimilate the message it transmits or receives [63].

In the quest to understand human behavior through interaction and information exchange, researchers work from approaches such as psychological or social, but others are convinced that another vision is needed [64] because of the complexity of that interaction in the real world involved. This is where the principle of multidimensionality appears in Virtual Reality, because to virtually represent that world a unidimensional approach is not enough, and because the better the understanding and analysis of the immersed complexity, the more realism can be added to the design of virtual systems.

Based on this, it was decided to apply a different tactic to resolve complexity in interaction, i.e., a multidimensional conceptual framework. For example, Allen [65] identified four dimensions to be addressed: cognitive, social, socio-cognitive, and organizational; Sonnenwald [25 incorporates cognitive, social, and system perspectives into one framework while integrating the concept of transdisciplinary to define the information horizon or space in which the actors interact.

On the other hand, Lamb and Kling [66] use a framework of four dimensions: 1) organizational and professional relationships (affiliation); 2) stabilized, regulated, and/or institutionalized practices (environment); 3) information, resources, and means of communication (interactions); and 4) representations of the self and profiles of actors as individual and collective entities (identities).

In any case, multidimensionality is a principle that has proven useful in the design of virtual worlds, with a level of improvement in terms of realism and sensoriality. Figure 5 shows the principle of multidimensionality according to Fidel et al. [67].

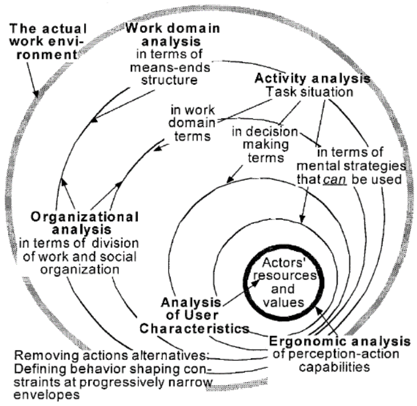

Figure 5. Interpretation of multidimensionality in Virtual Reality [67]

4.7 Dynamism

According to dictionary definitions, we could say that dynamics is a branch of physics that studies movement about the causes that generate it, that is to say, it is the set of forces that act with a specific purpose. But this meaning would lose meaning in the phrase: *He is a dynamic person* because here it would be understood as a quality that allows him to be in constant transformation. On the other hand, Virtual Reality, it is assumes the capacity for transformation and adaptation that the elements of the virtual world have, in such a way that the user can experience a higher level of reality about what he/she would obtain in a static virtual world.

This principle confers a high degree of realism to the virtual world so that the brain can grasp it as very close to reality. In addition, because in the real world, most of its elements are dynamic, it is also necessary to achieve an approach to the staticity and the amount of dynamism that is imbued to the virtual elements, because not everything moves and, when they do, they do not have the same rhythm. So, dynamism is an important principle in virtuality that adds a sufficient level of reality to bring the brain into a simulated reality.

On the other hand, philosophy is conceived as a theory according to which the phenomena of matter or mind are developed by the effects of the action of various forces, rather than because of the movement of matter. The basis of this theory is the understanding that matter is made up of simple and indivisible units, substances, or forces, as well as involves the theory of activity as a concept of interaction between them.

This theory considers the context (virtual world) as a dynamic system of work/activity in which the complexity of media, histories, cultures, artifacts, and motivations of activity in the real world is represented [68]. The unit of interaction in this virtual system is the human activity that involves objects collectively through a goal [69].

From this theory, it is possible to understand and analyze the phenomenon of virtuality to find patterns, make inferences, and describe phenomena, because, in the virtual world, each activity is an interaction that has a purpose that is achieved using tools. The latter externalizes the mental constructs of the author and the actor in the virtual world by transforming their internal and external cognitive processes used in the interaction [67].

Figure 6 describes the dynamism that can be achieved in a virtual world from the activity theory, where it is possible to describe actions in the system through a series of interrelationships between the actor and the environment.

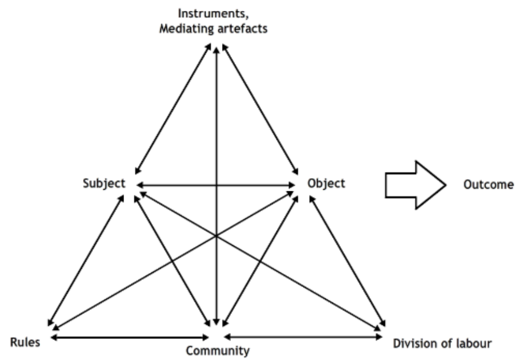

Figure 6. Dynamic interaction activity system [70]

4.8 Multimediality

This principle has evolved along with Information Technologies in various scenarios, such as education, advertising, communication, and cinema, among others, which has allowed it to be understood not only as a technology but also as a scope [71]. One definition of the term states that it is the interconnection of several of the functions provided by the media to achieve the objective of communicating. This can be evidenced in each of the scenarios presented, for example, in the combinations of text, images, sound, and video that can mimic reality. In the case of Virtual Reality, the construction of worlds is based on the digitalization of numerical data [72], mediated by technological tools that allow their production, storage, and retrieval.

One of the most important characteristics of multimediality is the recurrent way in which it uses the media in digitalization. In a virtual world, it is possible to find a miscellany in which they coexist in harmony regardless of their origin or objective in the system and help the designer in the sense of offering diverse combinations for each world he structures. Moreover, in this new world, transmitters and receivers coexist harmoniously while exchanging roles or creating new ones. This is achieved thanks to the fact that virtuality does not occupy a specific material space, so you can play any role you want without the limitations of the media in the real world.

Another characteristic is convergence, or the possibility of finding in the same space a series of media that can be used to shape the virtual world, with the advantage of not having to build them every time they are needed due to their immateriality [73] and of manipulating them to tell or represent other stories, in such a way that they come closer to the reality sought by the user. To evaluate the principle of multidimediality in a virtual world, several proposals have been presented, for example, Wise and colleagues [74] describe links, convergence, and updating; Paulussen [75] proposes the level of recognition of images and audio and video signals; and Kiousis and Dimitrova [76] differentiate three levels: 1) low: text only, 2) medium: text and images, and 3) high: video with text and images.

Finally, multidimediality requires a good narrative that involves all the necessary means to virtualize the real world that is to be represented. This characteristic refers to the need to convince the brain of the immersion in reality by harmonizing the media, the message, and the digitalization of that world. What is complicated in this case is that the real world is multimedia, because people live in scenarios in which sounds, images, movements, texts, and other people converge, building the real reality on which they develop their activities.

Therefore, Virtual Reality should take you away from that reality and take you to a new world in which you can have, in a certain way, better control over the objects of the scenario you want to inhabit.

4.9 Multiplicity

In the various domains in which the term multiplicity has ascendancy, a common relation of its meaning is found around the quality of manifold or multitude. For example, in mathematics, it is a class of objects in which any of its members can be completely specified using ordered numbers, which represent the properties of that element. In philosophy, two types of multiplicity are distinguished: the continuous and the discrete, to which a series of characteristics are assigned to find their distinction: the first is qualitative, virtual, continuous, and simultaneous, while the others are quantitative, real, discontinuous, and successive. On the other hand, in Computer Science it refers to the number of instances that a class has about another in the programming domain: one-one, one-many, many-many, and many-one.

As a principle of Virtual Reality, multiplicity relates to presence and space in the virtual system. In them the duration of the progressions and the multidimensional interrelations on the created space are given from multiple points and through multiple media, all mediated by a geometric idea. These relationships, between objects and their durations in space, materialize in degrees of immersion that indicate to the brain the direction in which the virtual world turns and, therefore, where each scenario is constructed and de-constructed. This property makes the user understand the space and the duration and nature of each multiple-element as virtual complements in his Virtual Reality. But here we must differentiate between virtual and real multiplicity, in the sense that the former is framed in a specific duration in the virtual scenario, while the latter in a plurality of times corresponds to each line of action that the user executes in his natural scenario. That is, in the former the duration of the multiplicity is controlled by the objective of the immersion, while in the latter it is not possible to do so given the nature of reality.

In the same sense, it is also necessary to differentiate between the logical multiplicity, which characterizes the user's expectation of the virtual world and which is materialized in it through the geometry of the visual and Euclidean spaces, and the logical multiplicity of the phenomena observed and felt. In this way, a combination is achieved between the characterization of forms and the diversification of contents to respond to the actor's objective within the virtual world, that is, a disconnection from the real reality is offered to live the virtual reality. Furthermore, by losing its static condition, the multiplicity achieves that the user reaches a visualization of dimensions and not of correlations of the new world so that its expression and position are no longer surprising because the brain is convinced of inhabiting multiple scenarios.

This experience in a visual Euclidean space with a high degree of virtual reality removes the measurement factor as a component of immersion because the uncertainty of not being able to differentiate the virtual from the real is simply an extension of what multiplicity achieves in the brain. That is to say, each visual contemplation becomes an objective dimension that forces the sensory system to stay within a coordinate system, under the risk of abruptly exiting virtuality.

4.10 Flexibility

According to the context, this term has different meanings, but in Virtual Reality, it is assumed as the ability of the elements of an environment to easily adapt to the needs of the design, the objective, and the level of immersion to be recreated. The variability of these components must be taken into account, so flexibility must be dynamic, as well as adaptive, although controllable in the sense of not losing sight of the objective of the virtual world. On the other hand, psychological and personality issues of the user must be involved, because the reflection of these will make the avatar adapt or not to the structure of the virtual environment. This fact decreases the level of flexibility to inhabit the world while affecting principles such as immersion and multidimensionality, among others.

According to the taxonomy that Schonenberg and colleagues [77] propose for flexibility, the following adaptation in Virtual Reality can be determined: 1) *of design*, or ability to incorporate alternative scenarios according to the user's predisposition and emotion response options, i.e. everything is possible as long as it is not forbidden; 2) *of path*, or ability to change an established route without altering the goal of the virtual world, as long as the user has authorization to do so, or an exception in the context leads him to take a deviation not previously established; 3) *of completeness*, or ability to execute a specification for which there is insufficient information, i.e., ability to self-complete a given specification, by direct or indirect relation and according to the user's sensitive and emotional responses; 4) *of decision making*, or ability to modify a process at runtime, which refers to the ability to modify an initial definition to adapt the virtual world to the changes generated by any of the above flexibilities.

On the other hand, the *homunculus* concept must be integrated into the flexibility of virtuality, because it represents an image of the user in which the relative sensory space of the cerebral cortex is reflected. This flexibility is fundamental in the control of avatars because different degrees of freedom of the real body are required. After all, the homunculus is a map of the body in the brain that takes advantage of the virtual world to represent locomotion through the avatar. Being a human characteristic in which the brain has a high prominence this flexibility will be affected in case the user has some cerebrovascular injury that can change the sense of where his body begins and ends, which will be reflected in the locomotion of his image in the virtual world. Then, in the design and structuring of virtual reality, it must be taken into account that the body schema of this type of user cannot be altered through sensory inputs. In many countries, this is considered unethical because of the consequences it could have on the brain of someone who, for example, does not have one of his or her arms.

4.11 Immateriality

In real reality objects are intentional, that is, they have a reason for being in every scenario in which they are used or appear, but in Virtual Reality, they have to fulfill a specific role, or not exist at all. This is due to the consumption of technological resources incurred when scenes, images, or contexts that have no intentionality in the real world are included. From this arises the concept of immateriality in VR or the digitization of objects through technological developments. It is about transforming material information into an abstract concept that only exists outside reality but is presented to the user in a context that guides their senses to accept it as tangible. This principle, in conjunction with those previously mentioned, marks the transition from traditional theories of perception based on the real, such as aesthetic, permanent, original, material, and true, towards a communication devoid of them, but imitated through technology.

One issue that immateriality pays special attention to is the fact that, in virtuality, it is possible to represent characteristics, principles, qualities, and scenarios that are impossible in reality, for example, mythical animals, alien beings, or spaces in any region of the universe. The care here refers to leaving an edge of disbelief so that the brain can disconnect from Virtual Reality without suffering any alteration. Moreover, theorizing the body in its virtuality implies accepting it as an interpretation of the material, but more flexible and socially more determined than its counterpart in real reality. This immaterial embodiment generates mixed feelings in users because they are virtual fictional heroes, recognized and admired, while in real reality they may live in isolated worlds with drawbacks of recognition and affection. Although this alternative intelligibility allows the body itself to be used as a conceptual tool, it is still the sum of theoretical propositions that create new modes of perception, which in turn structure the user's understanding and, therefore, new experiences of their body that they cannot feel in reality.

For all these reasons, immateriality is a powerful principle of Virtual Reality that can have advantages as well as disadvantages. All material artifacts, real or not, that can be digitized in a virtual world expand people's environment and daily activities, and have therefore become a cultural phenomenon in modern society. That is why they acquire meanings and functions and, as part of the world, affect real events and the lives of individuals. In other words, immateriality has led to virtual objects being accepted as real in actual reality, because they have similarities with real-life artifacts, although, in the traditional sense, they are devoid of physical properties.

Although this statement is true, current technological developments make it possible to model abstract artifacts that, although they have no real reality, often contain components representative of real-life objects, such as physical properties of color, length, and movement, depending on the environment in which they exist. But, due to their immaterial nature, they may also contain properties imperceptible in the real world, such as sounds, smells, or expressions. On the other hand, immateriality can give them an exchange value that confers them to the quality of products, in the sense that they can be traded and generate a virtual economy that mimics the real one.

5. CONCLUSIONS

As previously mentioned, research in Virtual Reality is a relatively new area, and the theoretical and experimental contributions and results are increasing every day. In this sense, in this research, we found several approaches that have tried to find and define the principles on which VR is structured and works. The research is still in development and the results presented in this chapter reflect the emergence of new concepts while intermingling with existing ones.

The questions posed in this research are oriented to finding and defining these principles, although, so far, it cannot be affirmed that the ones found are the only ones. On the other hand, the issue of the effects of these principles in people's real lives is analyzed, taking into account that Virtual Reality can generate conflicting sensations between the real and the virtual. Although its usefulness cannot be denied, especially in domains such as training, learning, and patient recovery, living in virtual worlds has side effects in real life. This is because the organ that receives the most influence is the brain, wherein a moment human beings organize or throw away their whole life.

All the principles of Virtual Reality analyzed in this article are interrelated and, to offer a sense of real experience inside a virtual world, it is necessary to enhance them to achieve the objectives of the experience to a great extent. However, although the use of VR is rapidly expanding in society, many authors call attention to the effects that this trend could have on people's lives, from isolation to the abandonment of affection for the real and familiar world. This does not mean that it should be abandoned as an area of research and development, but it does mean that it is necessary to exercise stricter control over the use that people make of it.

Another issue that can be concluded from this work has to do with the possibility of diversifying the use of the principles analyzed because authors were also found who relate them to activities such as architecture, engineering, and innovation. Although it cannot be stated that an interrelation on the same scale as offered in VR is required, some can be combined according to the need and the area of intervention. For example, in the case of functional and structural software test automation, the user would be replaced by an avatar in charge of running the system in a simulated business environment, while another one goes through the code looking for grammatical or mathematical errors. These possible applications of Virtual Reality principles, in combination with others from different areas, are proposed as future work for the research team.

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XI
Development of logical-interpretative and abstractive capacity in engineering students

The objective of this work was to carry out an analysis of the research about the development of the logical-interpretative and abstractive capacity, oriented from the visions of engineering, psychology, and philosophy. The methodology that we applied was a review of the literature, structured through a scientific protocol of search, analysis, evaluation, and synthesis. The final sample includes 71 papers distributed among empirical studies, case studies, and experiments. We find that in this area the work is intensive and receives wide attention from the community, but the results still do not meet the formative expectations of the students. The conclusion is that it is necessary to innovate the processes and initiatives to develop or enhance this capacity, especially in the engineering disciplines, to adapt and apply it in problem-solving and to the demands and needs of the current context.

1. INTRODUCTION

Logic is conceived as the formal systematic study of the principles of valid inference and correct reasoning, a science that is used in most intellectual activities but that is studied and applied principally in the fields of engineering, philosophy, psychology, mathematics, and Computer Science CS. Logic is important because it helps to reason correctly [1]. *Abstraction* is the process of thinking through which the unnecessary characteristics of something are removed to reduce the set of essentials; that is to say, this is a strategy for simplifying details and for replacing ambiguity, vagueness, and lack of definition for specific environments [2]. In this process, the ideas are separated from objects, a mental activity that is important as a tool for reasoning, and that is used to reduce the complexity of things.

Both *logic* and *abstraction* are necessary for modeling problem solutions, one of the main functions within the daily tasks of professionals in fields like engineering, Computer Science, and mathematics, among others. Both are processes resulting from reasoning and brain functions because thinking minds apply them for identifying and integrating data and information. Acting as a whole, they constitute the ability to identify in a non-contradictory way the facts, the experiences, and the reality; separating them is to accept that there exists a dividing line between them, and recognizing that conscience is the rupture of existence.

As a result of this dichotomy, both logic and abstraction, would be far from reality [3]. Thinking is to understand, experiment, and identify the facts of reality and the truth of existence, is a voluntary and volitional act that does not occur automatically [4]), but thinking with logic-abstractive capability is a reasoning skill for identifying realities, modeling solutions and conclusions, acquiring knowledge, understanding problems and presenting solutions [5].

Most functions and activities performed by people have to do with applying these two principles, which in turn constitute the sphere of formality based on mathematics and support the construction and exploitation of the abstract interpretations that are modeled from generated knowledge. This supports people's needs, especially in the above-mentioned field, for developing an adequate logic-interpretative and abstractive ability for understanding, modeling, and solving problems within their work context.

The objective of this work is to provide a general vision of the research about the development of logic-interpretative and abstractive capability, for which is presented the result of a review of the literature related to studies, research, reflections, and practices about the concept of development of this ability. This is the result of the first stage of the research project called the *Development of logic-interpretative and abstractive capability as a basic component for engineers in their professional activities*.

2. METHOD

The method used for this research is the systematic review [6], in which different stages like planning, work identification, selection process, evaluation and classification, synthesis, and inferences are applied (Figure 1).

2.1 Planning

In the first stage, it was developed a protocol for the systematic review, specifying the progress of the process and the applied methodology. It also defined the search strategy, the inclusion and exclusion criteria, and the synthesis method. To achieve the goal of this work, we decided to analyze the results of the published research and its contribution to the development of this field of knowledge.

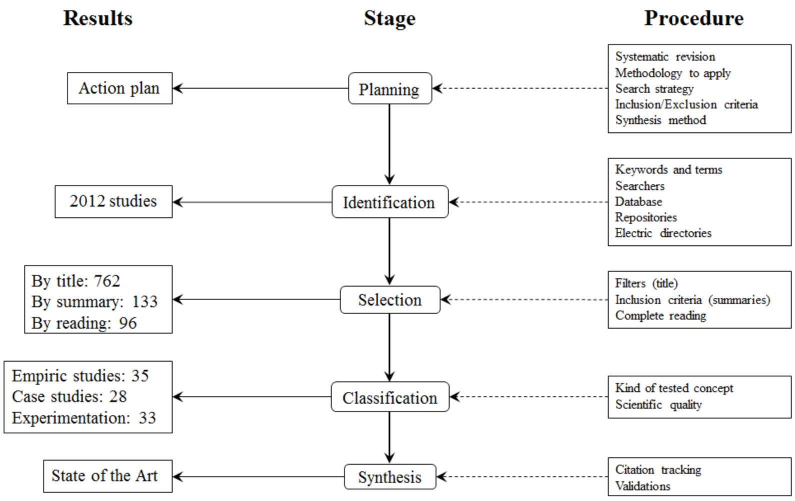

Figure 1. Research Method

2.2 Work identification

Systematic research began with the identification of keywords and search terms, which are presented in Table 1.

Table 1. Keywords and search terms

Keywords	Search terms
Psychology	Knowledge management, Knowledge creation,
Philosophy	Research, Development, Comprehension,
Logic	Application, Modeling, Experimentation,
Abstraction	Interpretation, Problem-solving, Case studies,
Engineering	Empirical studies

General words were used to identify the most relevant studies. In the process, we considered a huge amount of combinations between words and the search terms. Internet web browsers were used to consult databases, repositories, and electronic directories, whose content was related to philosophy and psychology. Some consulted sources, both free and by subscription, were DOAJ, Google Scholar, APA Database, Social Psychology Network, Science Direct, Generally Thinking, PhilPapers, Erratic Impact's Philosophy Research Base, Annual Review, FreeFullPDF, Philosopher's Index, and PsycARTICLES.

There was no defined line or time window to perform the search because preliminary results showed that studies about this field of knowledge have been conducted a long time ago, however, it remains valid. This process of identification shows 2102 studies that serve as the basis for the selection process.

2.3 Selection process

After identifying the population for this research the following filters were applied: 1) eliminating the works presenting duplicated titles or those not related to this review; 2) discarding the works that duplicated results and those that are not specifically related to the development of logic-interpretative and abstractive capability, and 3) removing those works whose research goals did not consider the visions of philosophy and psychology. This process reduced the population to

762 workers. They were taken the abstracts of these studies and were the following exclusion criteria:

1. The approach of the chapter is not oriented towards the study of capability development based on some of the visions.
2. The approach of the study does not address logic or abstraction.
3. Community does not properly support the method; tool or theory it describes.

After applying these criteria, the sample was reduced to 133 studies, which were quickly read, and at the same time, the exclusion criteria described above were applied. The final sample is constituted of 71 studies; their distribution is presented in detail in Table 2.

Table 2. Final sample distribution

Criteria selection	Quantity
By title	21
By abstract	25
By content	25

2.4 Evaluation and Classification

For this process two notions were applied: 1) examining what kind of concept was tested, for this was chosen the classification framework [7] for knowledge management strategies, and 2) examining the scientific rigor, applying the proposal of professor Jorge Allende [8]. Which states that modern science achieves its rigor through a set of approaches that ensure its progress and precision: 1) the works must be empirical and occur in the observable world, and to be considered as such it should contain a section describing the method and research context, 2) the processes must be verifiable and repeatable, and 3) the results must not appear as definitive tests, but as models of tendency. Because one of the exclusion criteria was the level of acceptance by the community, the categories for works are empirical studies, case studies, and reports of experimental results. This classification is described in Table 3.

Table 3. Sample classification

Criteria	Quantity
Empirical studies	35
Case studies	15
Experimentation	21

2.5 Synthesis and Inference

To avoid the problems derived from experimental results and interpretations derived from work without proper scientific rigor, sample articles were validated by monitoring the citations and validations made by other authors after their publication. For each study, the concepts discussed were taken, the main results and the research method, and the information used for representing the results were analyzed.

3. RESULTS

3.1 Logic and Abstraction

Some researchers in psycholinguistics and neuroscience emphasize the complexity of grammar and semantics of the language and orient their work towards the search for an appropriate comprehension level [9-13]. However, these works do not report to which extent people understand the logical meaning of the research subject, these works do not define explicitly the experimental situation applied, and they do not project the use of their results to propose changes in the educational processes. In the same way, as the age of the population increases, is also required detailed information about their linguistic habits and the logical comprehension they apply.

Suppes and Feldman [14] determined the way that children understand the meaning of logic connectors and logic itself, with this they contributed to the accumulation of systematic information. According to [15], some of the traditional problems of modern philosophy emerge from Artificial Intelligence. These researchers determined that a computer program acts *intelligently* if it has a general representation of the world in terms of inputs it must interpret and that for its design is necessary to know what is knowledge and how is obtained. Sloam [16] answered this work by arguing that philosophical problems about the use of *intuition* in reasoning, related through a concept of analogic representation for problems like perception simulation, problem-solving, and the production of useful sets, must be studied considering a specific way to act. However, in his work, he does not mention or apply logic-abstractive conceptualization as a basis for achieving it.

Boroditsky and Ramscar [17] opine that the ability to think abstractly is a necessary ability for professional development, but is common to find differences between students because some of them develop this ability faster than others, and some of them do not develop it. Other studies have demonstrated that exist links between abstractive ability and success in problem-solving, and these studies say that one of the educational goals should be developing it. The ability to think in this way was identified by Piaget [18] as one of the stages of cognitive development in children, and subsequently, he described the fourth and last stage of this process as *formal operation*, emphasizing that just 35% of children reach it.

[19-21] applied computational models for researching problem-solving, cognitive modeling, and long-term memory, and their results helped Kolodner, Simpson, and Sycara [22] explore ways in which case-based reasoning in cases can help for problem-solving. According to this model, the transfer of knowledge between cases is guided to a great extent by the same process of problem-solving. Besides, it demonstrates the interactions between solving processes and experience memory. The result of this work was a model of reasoning based on cases that integrate problem-solving, comprehension, and memory but it does not refer to how to integrate the mental logic-abstractive process that people apply for problem-solving.

[23] investigated learning and discovery, [24] investigated the processing of natural language, and [25] the diagnostic of errors. These studies helped Kumar and Venkataram [26] propose a model whose goal was solving diagnostic problems, based on the abductive inference mechanism, which was applied to add some new features to the existing general model for problem-solving. These researchers were the first persons who combined mathematics with computer algorithms. The results showed to be effective for solving diagnostic problems, but they do not approach logic and abstraction as tools that also work based on abduction.

Gottinger and Weimann [27] explored different inference techniques for a system that supports intelligent decisions based on influence diagrams, and they concluded that reasoning about action requires several levels of representation and inferences that depend on the level of uncertainty, depending on the complexity, and depend on the novelty of the decision situation. To perform this, they analyzed the works of Jarke and Radermacher [28] about the logic of problem-solving using techniques used for probabilistic analysis, decision-making under uncertainty, and operations research, and they analyzed the work of Gottinger and Weimann [29] about techniques based on Artificial Intelligence for systems supporting intelligent decisions. Although these works apply the logic from the vision of intelligent decisions, they do not deal with issues such as interpretation, problem modeling, or the abstractive ability of people trying to make these decisions.

[30] tried to find out if abstract reasoning is developed naturally and how educational processes contribute to this development. They focused on the effect that a prolonged training process has on the development of abstract deductive reasoning and the influence on the development of the understanding of logic needs. As a result, they proposed the hypothesis that, within a field of knowledge, emphasizing the construction of the meta-level of deduction can improve the development of deductive reasoning, both inside and throughout this field. The results of their research supported the theory that a prolonged educational process contributes to the development of logic comprehension, both for algebraic deductive reasoning and verbal reasoning of students. They also suggested that many teenagers, although exposed to the same processes, do not naturally develop this comprehension.

Two aspects capture the attention of the definitions of abstraction presented at the end of the last century: 1) the process of *detail elimination* for simplifying and focusing the attention on the most important issues, not considering one or more properties of a complex object instead of considering the other properties [31], and 2) the process of *generalization* for identifying a common core, based on the formulation of concepts for abstracting common properties of instances, and a general concept constituted by the extraction of common features from specific examples [32]. These issues served as the basis for subsequent research that tried to relate this development with the activities performed by professionals.

Pietarinen [33] tried to answer the question about what have in common epistemic logic and cognitive science, and he concluded that exist three possibilities: 1) new quantified versions of epistemic logic multi-agents capture the locutions of identification of the involved objects, resulting in applications of knowledge representation in the multi-agent system and parallel processing, 2) the framework of game theory semantics for the resulting logic have greater cognitive credibility like a true semantic for epistemic notions, and 3) some findings in cognitive neuroscience, related to the notions of knowledge and explicit transformation versus implicit processing, contribute to studies of logic. Pietarinen based on the perspectives of logic and cognition explored these connections.

[34] state that most adults need a *special environment* to reach the fourth stage of development of Piaget, but they do not clarify whether they reach this stage as a result of an inborn ability or develop this ability through the educational process they experience. Piaget describes this stage as *the logical use of symbols related to abstract concepts,* which also could be used to describe the ability to interpret problems and produce models, this is another of the goals that must be considered by the educational processes of this century.

Pietarinen [35] subsequently argued that empirical findings about rare neural dysfunctions are contributions derived from research on logic and that the early stage of cognitive science, whose origins coincide with those of pragmatist philosophy, share roots with phenomenology. Consequently, he identifies lines in this initial period that originated in logic, AI, and Computer Science. Another conclusion reached is that from these stages is also recognized the importance of the division between implicit and explicit aspects of knowledge on comprehensive cognition.

Although the contribution of his work is important for recognizing the roots of *logical disability* in some people, the results are not applied to indicate the same process for people without this disability.

Egorov [36] started from the hypothesis that the ability to think logically is determined by genes, which are informally called *logical genes*, which are responsible for encoding the information of proteins. He wonders if there are genes for logic in humans, and he answers that this is most likely because these genes contribute greatly to cognition control, as investigated by [37], [38], and [39]. In their model, a *logical gene* may work as a logic gate within a single logic neuron, which is also supported by the research of Sudarsan et al. [40] and France and Rumpe [41]. Egorov tries to find the origin of logical-interpretative capability in the people, and although their contribution is important it does not apply the same procedure to the abstractive ability, therefore is not possible to make a relational inference of the development of both capabilities.

Human beings are equipped with a powerful brain that provides them with consciousness and reflection, but a growing trend in psychology disputes the benefits of this consciousness. In this regard, [42] apply four studies in which they suggest that consciousness, as a reflection processing system, is important for logical reasoning, and they provide evidence that the reflection processing system also *helps*. They presented the hypothesis that logical reasoning depends largely on conscious processing, and they suggested that one way to test this theory would be to ensure that manipulations affect only one of two processing systems, keeping intact the other processing system.

There is an additional problem related to these issues, in the sense that students, despite the huge amount of information interesting for them, are not able to read it, analyze it, or critically evaluate it [43]. Bouhnik and Giat [44] developed a university course before this situation to enable students to apply logical tools. The course was developed for two different groups of students, one group oriented towards liberal arts and another group oriented towards exact science, and its purpose was to study and understand the logical systems based on the concept. The results showed that the skills in logical and critical reasoning of the participants improved over time, both objectively and subjectively. This work makes several contributions to the fields of ICT education, applied logic, and critical thinking.

[45, 46] stated that inductive, deductive, abductive, plausible, and transformation reasoning are derived from disciplines related to education in mathematics, such as philosophy, psychology, and mathematics itself. Subsequently, [47] considered the general distinction between inductive and deductive reasoning, from the philosophical tradition and from different disciplines and contexts in which this distinction persists, and they focused their research on the inductive reasoning process. Ibañes [48] and [49] highlight the practical difficulties of performing this distinction. The researchers concluded that students apply logical actions more frequently in problems whose particular cases are expressed numerically and that students can identify the applicability of certain steps of inductive reasoning they have previously used in classrooms.

Halpern and Pucella [50] examined four approaches for addressing the problem of logical omniscience and their potential applicability: 1) syntactic reasoning [51, 52], 2) conscious reasoning [53], 3) algorithmic knowledge [54] and 4) of impossible worlds [55]. Although for some researchers these approaches have the same level of expressivity and can capture all the epistemic states, others show the opposite. The objective of the research of Halpern and Pucella was to deal with logical omniscience, that is to say, how to choose an approach and construct an appropriate model. They concluded that the impossible world's approach is *particularly suited* to represent a subjective point of view of the world.

Recently emerged the interest in researching the issue of collecting evidence about the links between abstract thinking and the development of abstract ability. Some researchers conclude that logic and abstraction are *key skills* for education in Computer Science [56, 57], and others try to find a link between success in computational logic courses and abstraction skills [58, 59], all of them with varying success.

3.2 Logical-interpretative and abstractive capability

According to [60], to be logical is needed: 1) have sensitivity for language and have the ability to use it effectively, because logic and language are inseparable, 2) have respect for the world stage, because logic is about reality, and 3) having a keen awareness of how ideas are related to objects in the world because logic is about truth. Effectively developing these skills, attitudes, points of view and practical variants allows to any person prepare his mind for working successfully with logic [61] (Table 4).

Table 4. Details the features a person must have

Features of a logical person
▪ Be an excellent observer
▪ Be aware
▪ Get the facts directly
▪ Understanding the ideas and their objects
▪ Be aware of the origins of ideas
▪ Matching ideas with facts
▪ Matching words with ideas
▪ Performing deep analysis
▪ Concatenating situations for drawing conclusions
▪ Communicating effectively and efficiently
▪ Avoiding vague and ambiguous language
▪ Avoiding evasive language
▪ Having concentration
▪ Be realistic
▪ Searching for the truth
▪ Communicating in different ways, not only verbally
▪ Be a good listener
▪ Be a good reader
▪ Writing well

Cognitive psychology deals with thought but focuses on descriptive theories that study *how* people think in practice, regardless they think correctly or not. Some of these theories have been developed isolated and have little relation to each other, however, several psychologists have developed other theories, such as the *dual-process* theory, which is a combination of descriptive and normative theories [17]. The first one focuses on intuitive thinking, which from the perspective of the dual processes is developed in a subconscious, associative, automatic, and parallel way. The regulations focus on deliberative thinking, which is based on standards, that require effort and are conscious and serial. Therefore, is deduced that logic is related not only to abstract thinking but also to thinking shown in the form of sentences and the one that manipulates sentences for creating new thinking.

Therefore, if logic is a formalization of human language, the best place to find it would be in the brain [62]. But limiting the observation to the structure and activity of this organ would be as analyzing the hardware when the target is the software, or as trying to understand human interactions by studying the motion of atomic particles, therefore common sense must be used and we must have as basis the introspection, although unreliable [63]. Excessive optimism can lead to looking at what you want to see instead of seeing what is there, therefore psychologists of the first half of the XX century, suspecting this introspection, completely forbade it [64].

Artificial intelligence offers an alternative approach to discovering the language of thinking and uses the construction of computer programs in which inputs and outputs simulate externally visible manifestations of mental processes [65]. To the extent that success is achieved in the simulation, it will be possible to consider the structure of these programs as analogous to the structure of the brain and consider its activity as analogous to thinking. However, different programs having different structures and modes of operation can show similar behavior [66].

Some are closer to the lower and specific level of hardware and they are more efficient, while others are closer to the higher and more abstract level of the application domain and are easier to understand. If human thoughts have the structure of language, it could be achieved an idea of it by looking at natural languages, such as the Spanish language, or the way people communicate in situations where they do their best to express themselves clearly, coherently, and effectively. Besides, it would be possible to obtain a guide from the recommendations found in the books of style.

Now, according to these theories and research, which would be the logical-abstract capability people depend on for their cognitive development? How can be improved these capabilities? It would be possible *to teach* skills of logical-abstract thinking? Trying to answer these questions and based on case studies, [34] and [67] established the foundation for a better understanding of cognitive development, for they proposed four stages: 1) sensorimotor, 2) pre-operational, 3) concrete operational, and 4) formal operational. In the first two stages, intelligence is demonstrated first through motor activities, then with early language and symbol manipulation. In the third stage understand the conservation of matter the understanding of causality, and the ability for classifying concrete objects. In the fourth stage, it is shown an ability to think abstractly, systematically, and hypothetically, and symbols are used related to abstract concepts; i.e., is a crucial step in which the individual can think abstractly and scientifically.

However according to the results of some studies and experimental evidence, it seems that not all people progress to the formal operational stage as they grow up [68]; moreover, for teens and adults to achieve this stage it can be necessary for some particular environmental conditions and educational processes. Hall [69] says that logic allows humans to examine ideas, concepts, and mental processes because it can be found in all the spheres of ordinary life where logical thinking is expressed using logical relations in natural language, a principle that is necessary for simplifying and understanding everyday life. Wason and Johnson [70] say that the understanding of rules and regulations has become a problem affecting people's lives. The issue is being able to develop logical-interpretative and abstractive capability in each person, in such a way that persons can interpret the world from the context surrounding the development of their life.

4. DISCUSSION

According to the vision of *psychology* in the state of the art, thinking systems throughout time establish trends trying to explain the universe and the human being. In the modern era, it consolidated a worldview that atomizes phenomena to build theories, and from fragmentation, and supported by the experimental method as a verification tool [71], tell us about the details and create a set of micro-worlds that seem to live independently within the world they belong to. In this regard, a psychology based on the development of cognition and defined as the study of human behavior is proposed because to be recognized as a science it must propose an object of study observable, measurable, and verifiable through experimentation [72].

Although these principles have widespread acceptance, in the history of human thinking is not found a unique acceptance of the universe. Simultaneously, other views, having this way of thinking and coming from positivist positions like those from Freud and Piaget [43], realize the impossibility of explaining the psychical-human only by the measurement, which tries to homogenize the object of study to establish laws as a scientific product. From this comes another certainty: the human being, like the universe, cannot conceive mono-causally [49].

According to these principles is difficult to analyze the development of logical-interpretative and abstractive capability from an exclusive view between genes and education [42], even though genes or education. It is a theoretical construction, involving a meeting between multiple agents derived from the biological, cultural, and contingent axes, that intersect themselves to create an interaction that makes possible the emergence of subjects as a result of a dialectical encounter. Thus, thinking logic and abstraction is a task that must result in a conception of the object of study. That stays away from exclusive paradigms for nominating itself from inclusion with general, particular, and unique categories, and using psychology proposed as a scientific discipline dealing with the study of etiology, psychological and mental processes, and their products (conducts) [73]. Thus, the initial conjecture, about logic and abstraction mental processes, is that they are the result of the transforming encounter between biological nature, cultural condition, and contingency, which must be analyzed based on specific environments such as those of Engineering and CS.

Throughout history, and based on the result of this review, logic has been addressed as a description of the laws of thinking, which rule the ways to behave and to distinguish between what is considered false or true. Thus, logic indicates *how* to think about some ideal, determined by society, through a scientific discipline, or a series of consensus and standards. From the point of view of psychology, inductive and deductive reasoning are closely related to logic, to the extent that they allow explaining the ways of reasoning and abstraction, considering inductive reasoning as the task of obtaining conclusions from premises, prior knowledge, and contents. Therefore, logic is the result of the *ability to think* and other mental intellect, which in turn leads to reasoning and problem-solving.

Thus logic, reasoning, and abstraction are cognitive processes that allow transforming numerical, non-intelligible, and abstract information into practical solutions, and in this process of solution construction, plans, and knowledge persons play an active role [57]. Based on the premise that logic is the framework and guide for studying the thinking of subjects [74], two approaches can be considered: 1) the *logicist* approach, which states that when reasoning is performed we use a set of abstract rules, and 2) the *semantic* approach, which focuses on the development of mental models. That considers the meaning of the contents over which human reasoning operates, in such a way that there is a relation between the meanings of mental representations with the outside world. From these approaches, it is concluded that the ability for problem-solving does not depend on general search strategies, but depends on a rich background of specific knowledge [65].

In this context, professionals are faced with different problems and critical situations they must solve, this requires from them a permanent intrepid attitude and thinking ready for solving these challenges and elucidating concerns, therefore is an effect related to dispositional attitudes, motivations, commitments, and the ways of thinking of people. Thus, possibly there is an aversion to the complexity and problematic issues, those on which people do not want to have either analytical or logical reflection [75]. In this sense is emphasized the role of desire and the role of emotions like curiosity, love, and truth, guide the thinking and reasoning in daily professional work activities.

All the issues above mentioned indicate the importance of logic in human performance within the world because people need to show their *logical ability* for problem-solving, and their *proactive and evaluative ability* for creating designs and plans, which must become real according to ideals and social needs [73]. A type of thinking in action allows them to represent external reality and act efficiently, recursively, and ingeniously on it. Possibly the combination of experiential, internal, emotional, and contingent agents, will provide them with a proper application of logic for their creative and thinking activities.

Most humans solve problems coming from different sources, either because these problems were proposed to them or because they auto-recognize them, but despite the source, the problem comes from, someone with a degree of ability tends to understand the scope and objectives of the problem, before facing their solution [76]. This is not always the same; for example, engineers must apply their intellectual abilities, shown in their logic-abstractive capability, to understanding the problem, modeling, and solving it. Furthermore, the problems they solve do not have the same level of complexity as other-profession problems and engineers' problems often start with an unclear statement, therefore engineers must identify problems within their environment and define and represent them in their minds [55] (Table 5).

Table 5. Process of problem-solving in terms of a cycle consisting of a series of stages

Stages for problem-solving
1. Recognizing and identifying it
2. Defining and mentally representing it
3. Developing a solution strategy
4. Organizing the knowledge about it
5. Assigning physical and mental resources to propose a solution
6. Monitoring the progress of the proposal for reaching the target
7. Evaluating the efficiency and effectiveness of the proposed solution

This cycle is descriptive and does not imply that all problems are solved sequentially through all the stages following this order. On the contrary, the mind must be structured in such a way that, by applying these stages, it will be possible to solve problems successfully. Moreover, the mind must be prepared because in general terms the solution of a problem leads to another, which must be solved by a similar cycle [77]. That is to say, problem recognition, definition, and representation are mental processes of the executive level, called meta-components in the theory of human intelligence of Sternberg [78], which guide problem-solving by process planning, monitoring, and evaluation. From psychology, and applying the process of meta-components, problem-solving is a task performed by people with proper education to perform it. The difficult issue in this process is that most problems are poorly defined, therefore is necessary to clarify their range, scope, and objective, continuing in the same way.

Although well-defined problems have a clear path to finding their solution, the solver must determine the strategy, and to develop this strategy he must apply its logical-interpretative and abstractive capability. Furthermore, he must be clear that the problem has a representation in the physical world, and that he must abstract the problem to improve their understanding of it and for structure and deliver an efficient and effective solution [79].

From the perspective of *philosophy*, and using the overall understanding of the realities based on the *episteme* or theoretical universal and necessary knowledge of human beings. Which corresponds to the abstraction or the essential notion of things, the *philosophy* is the antecedent that is reached through finding common threads or vertices by distinction, and through eidetic essences covering the whole. Although this is often assumed, philosophy does not stop there but generates *techne* or application of knowledge to a particular task like engineering, which deals with a knowledge that has to choose the appropriate means for achieving its goals, because of the *techné* searches for a product. Another dimension of philosophical knowledge is *phronesis* or practical philosophy, which guides taking positions and the set of attitudes and actions of men in contingencies, i.e. the changing realities and problems requiring decisions and solutions because knowledge helps him while being and doing because without *phronesis* men could not act effectively in contingencies.

If these three dimensions of knowledge are not integrated, we could hardly speak of logic, because we can have *episteme* but we have no interest in applying *techne*, to choose the appropriate means to achieve goals or get products. In other words, a person can experience requirements for producing, but this person can have no interest in using practical philosophy or *phronesis* to commit himself as a person who analyzes and solves problems and that creates innovations.

At the different levels of gnoseological education, fragmentation is usually performed between the old formal logic (Greek-Aristotelian), Galilean logic (Italian-Mediterranean), empirical-associative logic (English), and analytic logic (French-Cartesian). Especially when the last ones try to surpass the syllogism logic, what Bacon called the *barren philosophy* of works and instruments for winning in disputes, and that tries to substitute the philosophy of words with the philosophy of works. Similarly, Descartes confined it because of its *inability to invent* and because it is a redundant method and not a discovery method, which seeks *fixed rules* for *discovering truths* and not for defending a thesis or explaining theories.

This breakup can be the missing link in gnoseological education at different educational levels, especially in fields whose influence is greater, which results in an irreconcilable binary opposition. In this process, syllogistic logic is used by spontaneous generation, and we jump towards symbolic and mathematical logic, which are adopted in a fragmented and isolated way.

Without understanding that there is the same gnoseological route running from the simplest to the most complex issues, and vice versa, in the same direction as the third rule of Descartes' Discourse on Method. According to this thoughts must be developed in order, starting from the simplest and easiest objects to know, to gradually ascend to the knowledge of the composite object, and even assuming an order among the objects that do not naturally precede each other. This rule, given the complexity of the epistemological resources of education in some fields, constitutes a *microscopic* [80] and inescapable starting point for potentiating or developing the logical-interpretative and abstractive capability of students.

Hermeneutics is isolated and opposed, without recognizing this ability as a gnoseological resource a priori -*experimentum*- for generating hypothesis, or as a *post-experimentum* resource, which imposes discipline to fantasy, to find relevant data and underlying senses, which result in products and solutions, as in the case of engineering work. Besides, it makes deliberately little use, maybe because of ignorance, of the all-embracing freedom of American pragmatism, which does not ignore hybrid or possible combinations when testing solutions and that tries to find vital and procreative ideas that multiply themselves in thousands of ways, and which spread producing progress in civilizations and constituting human dignity. Something that for today's society seems to have little importance.

This is not about the goal of relating students to a philosophy of fundamentals or a philosophy looking to the past, this is about showing them the possibility of re-description -the contemporary logic option-, not for repeating philosophy but for advancing. About the American neo-pragmatism, Rorty [81] states that the purpose of the university and the goal of education is not only *producing* a good professional but also achieving that people *get free imagination*. Probably, the best way to achieve that people use imagination is they know the imaginative ability of the authors of philosophy, science, arts, psychology, and engineering and thus they could discover the importance of developing their logical-interpretative and abstractive capability to contribute to this society.

5. CONCLUSIONS

One of the objectives of educational processes is to prepare the students to adapt flexibly knowledge to new problem situations and their configurations, therefore their ability to understand and model problems provides an important index of training that can help them to evaluate and to improve these processes [82]. Some pedagogical approaches search for equivalences, although their only learning metric is measuring the ability of students to memorize the concrete information that is presented to them. The educational differences become more evident when evaluating how well this education is transferred to the solution of new problems and configurations, that is to say, to problems faced in professional life. This analysis is discussed in most research of this review, and it constitutes evidence of the need for developing the logical-interpretative and abstractive capability for knowledge creation and achieving the learning objectives of this century.

Some important features of these processes affect the student's ability to transfer what they learn. One of them is the amount and type of initial learning they require to develop experience and abilities to transfer that knowledge. However, if problems they face do not attract their attention, their ability to understand these problems decays, and decays more their ability to solve these problems. The studies analyzed in this review suggest that educational processes must use Problem-Based Training, as close to daily life as possible, because in this way the students develop much better logical skills for understanding problems, and the abstract abilities to model them.

Furthermore, the context in which they are educated is also important to ensure this transfer of knowledge. According to the results of the analyzed research, is less probable that a student, educated within a single context, achieves the goal of the course, which may vary when this student is exposed to multiple contexts. In this way, he has more possibilities to understand and abstract the relevant characteristics of the problem and to develop a more flexible representation of it, which must become an educational goal for institutions.

If the goal of education is to provide professionals for a society that builds trust, it would be advisable to modify the learning processes they experience. The society of this century needs reliable professionals, who observe ethical and human issues, but mainly with the ability to be problem solvers. Society develops and coexists with problems requiring efficient and effective solutions, but according to the research conducted in this chapter, new professionals do not meet these requirements. Although until now is not possible to answer whether the development of logical-interpretative and abstractive capability is a genetic issue or is acquired through learning processes, we can say that pedagogical models, curricula, and existing programs are failing to potentiate this ability or properly developing it in students. Therefore, important changes are needed for each one of these concepts.

Psychology and philosophy have made important contributions to the achievement of this goal, as shown by the results of empirical and experimental investigations of the state of the art. The recommendation is to adopt them based on the structure of educational solutions according to the needs of each context, because, according to the results, each person is a universe that has different educational motivations and different learning rates, and his everyday life occurs in different contexts. For all of these reasons, and the current Information Society and Knowledge Society, we require processes and initiatives to potentiate or develop the logical-interpretative and abstractive capability of students, in such a way that they adapt this ability according to their requirements and particular needs.

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XII
Artificial Intelligence, sustainability, and ethics for the survival of humanity

Working on and contributing to sustainability is generally considered to be a good and important thing for humanity, so it is also conceived as a matter of ethical importance. This chapter aims to analyze the different ethical dimensions of what has been done so far about Artificial Intelligence AI and sustainability. The results show that most of the work done focuses on the preservation of the environment as an option in favor of the survival of humanity, but this study goes a step further in this sense and advocates for sustainability not reducing humans on the Planet because it is time to think about what will happen in the coming decades with the accelerated development of AI when humanity surpasses the borders and expands beyond the Earth.

1. INTRODUCTION

One of the characteristics of the 21st century is that the increase in the number of living beings is inverting the relationship between natural and artificial resources on the planet, i.e., while everything that can be considered natural is decreasing, everything that can be considered artificial is permanently increasing. To illustrate this situation, let us analyze, for example, what is happening with fossil fuels: on the one hand, remedying the depletion of this resource is one of the pillars of AI research, but in the search for solutions, new technologies are being developed with the idea of finding alternative sources for human survival. So, the question must be asked: will the development of artificial resources be enough to make up for the loss of natural ones, so that humanity will survive in the future? This perspective should be one of the goals for the ethics of sustainability of AI, but, as this chapter demonstrates, it is not the focus of the New Era.

While the essence of the term sustainability is not solely circumscribed to the ethical, it is essentially defined as a particular characteristic of systems as they change over time [1]. While in research and development, sustainability is used in ways that have no specific ethical meaning, in logical analysis it does acquire one [2]. Therefore, and from this perspective, in this work, it is assumed as a concept whose use needs analysis, because in everyday life it has connotations of something good that deserves to be sought [3]. Other authors think this way and have developed initiatives in which they assume the ethical relationship between AI and sustainability is necessary for human survival [4-7].

According to the arguments of the researchers, an analysis of the ethical dimensions of sustainability is warranted, as well, to answer concerns such as: What should be sustained? Why should it be sustained and for how long? By what level of importance should it be measured? And, while these questions can be answered in a variety of ways, how they are answered will have significant implications for human survival in the New Era, when the development, use, and governance of AI will demand greater attention.

Although this chapter discusses ethical dimensions of sustainability not specific to AI, it should be seen not as a mistake, but as a feature, since in general terms the ethical dimensions of both concepts are the same. Moreover, everything related and specific to AI has roots in more general sustainability issues, therefore, the authors understand that to analyze the sustainability ethics of AI, one needs to understand the ethics of sustainability.

The results presented in this chapter are a contribution to the growing interest of the community in researching the relationship between IA and sustainability, which is reflected in the growing related literature. Most of those works are oriented to the presentation and analysis of the correlation between both areas but are almost always aimed at analyzing AI, sustainability, and environmental aspects [8-10], environmental policies [5], risk and sustainability [11], the environmental footprint of technology [12] or SDG compliance [13-15]. There is also research on topics such as the sustainability of AI systems [16], the consumer [17], health [18], economics [19], social applications [20], and many others. As these examples demonstrate, a wide variety of work can be found in the literature on AI and sustainability, although the question of the ethics of sustainability is not much discussed.

On the other hand, this research aims to contribute to an underlying question in the literature related to the topic of sustainability ethics of AI for the New Era, which is not much worked on in research and little published. While it is important to dialogue and analyze the relationship of AI with sustainability, environment, health, and other areas, so is the debate about the relative importance of AI in the short, medium, and long term [21, 22], because, as shown in this chapter, the future of sustainability involves the use of AI with ethics. In this regard, the approaches of Tonn [23]), Brockman [24], Owe and Baum [25], and Adamson et al. [26] can be consulted.

2. SUSTAINABILITY AND ETHICS

The term sustainability was first used in von Carlowitz's [27] treatise and focuses on the sustainable performance of forestry. In more recent times one finds various works in which the word sustainability is referred to, but in which it is conceptualized only in socio-environmental terms, and has been widely published in search of a definition of sustainability and sustainable development [28, 29], thus diluting the concept in the literature. These attempts to find or impose a definition of the term often culminate in it being assimilated into good, leaving sustainability without any specific meaning [30], and a vacuum that corporations take advantage of to continue developing activities that drive environmental destruction and social inequity [28].

In all these attempts to develop a definition of the term, social, environmental, and economic, known as the three pillars of sustainability, have also been written about. But they have also not received wide acceptance because they are confusing and overlapping, and because they exclude other equally important ones, such as the cultural and the political, but, and this is most important for this chapter because they are not considered essential in the paradox of humanity's survival [5]. The point is that economic activities are social, and all human activity is itself an environmental issue; moreover, the authors associate sustainability with the need to protect the environment, but many of the current affectations can be dissipated in a short time and affect very little the survival of humanity. While issues such as education and economic growth, which have a greater impact on such survival, receive relatively less attention the so-called three pillars are not a solid reference for sustainability.

Philosophy makes its contribution in this sense from the intrinsic and instrumental values and affirms that things are valuable from the instrumental point of view when they are valuable by themselves or as an ultimate end in themselves, that is, they are valuable when they support others that are equally valuable [31]. For example, the wind is valuable, because humans can use it to generate electricity, which is valuable. After all, it is used to run technology, which is valuable, because it improves the quality of life of people, and good quality of life is good in itself. In this case, wind, electricity, and technology are valuable instruments, while people's lives are intrinsically valuable. This means that the definition of sustainability may vary depending on what it is intrinsically valued and on what instrumental values it is based on.

The reality is that definitions of sustainability can be considered anthropocentric because their intrinsic value only refers to the human [30]. This is the case of those that highlight the fact that in the future generations could be considered something other than human, or those that defend resources as necessary instruments for the benefit of people. One can also find ecocentric definitions that give intrinsic value to ecosystems or those that use it with other notions of intrinsic value and highlight issues such as that there is intrinsic value in the well-being of non-human beings, such as plants, animals, or even machines. The crux of the matter is that the distinction between intrinsic and instrumental is not always important, but sometimes they are, for example, reducing the greenhouse effect is as good from the anthropocentric as from the ecocentric.

Since this chapter treats sustainability as a necessary issue for the survival of humanity, we need to look at the issue of how long it needs to be implemented. The reason is that there is a big difference between making things sustainable for a few days, a few years, centuries, or forever, and this seems not to be taken into account in discussions about sustainability, ethics, and AI. At the end of the last century, future generations were talked about in terms of decades, because they were assumed to be human, but did not involve the number of them. With the advent of the 21st century, it began to be considered that future generations would not necessarily have to be human because digital began to rule in AI and the development of humanoids became a valuable scientific stream.

On the other hand, we also have to accept that sustaining intrinsic or instrumental values is good, but since humanity manipulates many of these values, we have to ask ourselves how good it could be. Here we have to involve again the concept of current and future generations, because many things may be good today, but not so good for tomorrow, and vice versa [32]. However, these assessments involving the intergenerational only analyze sustainability from the anthropocentric conception, although it is also possible to take into account other approaches. Hence the importance that sustainability is not considered apart from ethics and the survival of humanity, which necessarily leads to evaluating it by taking into account different moral issues that are located within the ethical principles of AI [33].

Likewise, other issues must be taken into account in the analysis of the relationship between sustainability, ethics, and survival, which in general are related to the effort that must be made to achieve the ethical objectives of AI. This issue is important in any moral debate, especially in those that relate sustainability to AI because it is not possible to ignore questions such as: how much effort should be made to promote sustainability? Is it a little enough or should everything be given? Is the mere fact of working on sustainability enough or should it be done in the best possible way?

It should also be noted that sustainability can be a criterion of optimization, which means that it is in the best interest of humanity's survival to seek to optimize the ability of ethics in AI to be sustained over time, which is different from optimizing its intrinsic value. On the one hand, sustainability alone is to allow things to be sustained at least in their minimal form, but optimization relates to making things the best they can be from the point of view of ethics. In other words, achieving sustainability alone should be the basic minimum standard of AI, while achieving optimization should be the highest ideal. This distinction has a direct bearing on the survival of humanity since today the call is being made for the present generation to act on global problems, but it should do so without compromising the ability of future generations to meet their needs.

The reason for this is that, if the actions of the current generation are not aimed at enabling future generations to do much better, the great opportunity to enable sustainability will undoubtedly have been squandered. This forces the development of AI to be oriented towards achieving higher standards of living, rather than just meeting the needs of future generations. That is, humanity does not rigorously need AI systems to drive vehicles or to implement lights-out industries because this falls outside the scope of sustainability, but it should improve food development and environmental protection.

3. ARTIFICIAL INTELLIGENCE, SUSTAINABILITY, AND ETHICS IN THE LITERATURE

After presenting the statements and arguments of the previous sections, the authors conducted a systematic literature review [34] of papers presenting results and analyses related to the subject matter of this chapter. Using the search terms: *sustainability* + *ethics* + *Artificial Intelligence*, both in English and Spanish, 234 published from 2014 were found, from which duplicates were extracted, yielding a sample of 168 papers. They were examined in detail to categorize their treatment of search terms. In most of them, it was only necessary to analyze the abstract and introduction to get an idea of what they deal with; for others, it was necessary to review the entire content in more detail. Of the 168 papers, 73 did not present results and analysis relevant to the search objective, because they did not sufficiently analyze the relationship between Artificial Intelligence, sustainability, and ethics, leaving a final sample of 95 publications.

Of this sample, 75% of the papers present results and analysis on the topic of environmental sustainability, including discussions about AI sustainability, business, human-AI interaction, decision-making, sustainable planning, sustainable health systems, social sustainability of AI, and sustainable development, among others. The other 25% analyze and intrinsically value only humans, human and non-human, life on the Planet, biodiversity, ecosystems, the biosphere, and the Planet. Among them, 12 take into account the time scale involving future generations and a defined timeframe. Only 4 publications analyze the relationship between ethics, sustainability, and Artificial Intelligence for the survival of humanity. The following is an analysis of some representative papers from the sample.

According to Bostrom and Yudkowsky [35], the possibility that it will be possible to create thinking devices raises ethical questions: how to ensure that they do not harm humans or morally relevant non-humans, and what their moral status should be. The publication presents 1) an analysis of the problems that may arise shortly from AI, 2) describes the challenges in ensuring that it functions safely, 3) proposes a method for assessing whether, and under what circumstances, moral status can be assigned to AI, 4) considers how to differentiate AI and humans in terms of ethical issues, and 5) addresses the problems that may arise in the future when humans may develop AI surpasses as them in intelligence and how to ensure that they use that intelligence for sustainability in an ethical manner.

Floridi et al. [36] report on the findings of the AI4People initiative, which aims to lay the foundations for a good AI society. The authors discuss the opportunities and risks of AI for society and propose a set of ethical principles, on which its development and adoption should be based, and 20 concrete recommendations for assessing, developing, incentivizing, and supporting ethical AI, which can be undertaken from both the public and private sectors. They conclude that, if these recommendations are firmly and decisively adopted, they will form a solid basis for the establishment of a good AI society.

To Jobin et al. [37], in this century private companies, research institutions, and some public organizations have disseminated principles and guidelines related to AI ethics. However, they state that, although agreements have been reached that AI should be ethical, there is still debate about what ethical AI is, and what requirements, standards, and best practices are required to achieve it. These authors mapped and analyzed the literature to find out the level of a global agreement on these issues, and found that such agreement seems to be structured around five ethical principles: transparency, fairness and equity, nonmaleficence, responsibility, and privacy, but that there is still no substantial agreement on how to interpret them. The positive aspect of their findings is that the analyses and discussions highlight the importance and need to integrate these efforts to structure guidelines with a substantial ethical attachment and adequate implementation strategies.

Schiff et al. [38] argue that by the second decade of the 21st century corporations, governments, and NGOs had produced more than 80 papers on AI ethics, and present an analysis of three issues that should be important for any of these publications: 1) the potential challenges associated with the relative homogeneity of authors, 2) the typology for characterizing the obvious and not-so-obvious goals of the publications, and 3) the various impacts they may have on AI governance.

For Gomee et al. [39] computational sustainability uses computation and AI for human welfare and protection of the Planet, so its planning and development must be carried out from complex Transdisciplinary decisions, revolving around ethical issues related to human welfare, infrastructure, environment, and different species. The authors highlight the intrinsic value of the non-human and the human alike, in an ethical sphere of non-discrimination.

Skaug [40] asks how AI affects the SDGs, and concludes that AI directly impacts humanity and nature, and the SDGs lay out the path for systematically assessing that impact. He concludes that it is necessary to understand and ethically understand the context of AI, i.e., base infrastructure, developers, owners, who accesses it, who uses it, and what it is used for, and not to digress into isolationist theories of AI, ethics, and sustainability. In this way, both the direct effects of ethical AI on sustainability, as well as second-order effects, are analyzed.

4. ETHICS, SUSTAINABILITY, AND ARTIFICIAL INTELLIGENCE IN THE LONG TERM

It is important to make the case for long-term oriented non-anthropocentric sustainability, so it is expected that related research will work strongly for intrinsic value optimization because the implications of this sustainability are the strongest foundations for long-term AI. At the same time it must be made clear that these arguments depend on certain positions on the underlying ethical principles, although, as with all ethical principles, it is clear that there is no consensus on which position to take. The point is that one may or may not agree with this position, but in doing so adopt a different one, so it is important to do so, especially when considering the implications for the ethics of sustainability and AI.

This argument starts from the assertion that the non-anthropocentric refers to the fact that humans should not be the only ones intrinsically valued, since it is widely accepted that they are part of the animal kingdom while being immersed in nature. Moreover, morally significant particularities, such as the desire to live and progress or to experience enjoyment and pain, are not unique to humans [41].

Another issue with which one may or may not agree is positions that value the non-human less and, although there might be legitimate reasons for this, intrinsically valuing humans more than other entities seems unethical and no morally valid justification is found for doing so. That is why long-term sustainability must be defined in the sense of also sustaining the non-human because everything on the planet is part of an uncertain future and no one has the slightest idea of what humanity will need to subsist in a few decades [25]. This position does not intrinsically value only humans, so it conflicts with common approaches to sustainability, but those views seem to be in moral error, and the call is for long-term work on sustainability and AI to include more than an intrinsic value of the human.

Similarly, it is hoped that in this long-term work, sustainability will not be thought of on a defined time scale, but as an ethical principle of equality over time. In this way, it will be achieved that no one or nothing feels disadvantaged by existing in a particular time, that is, people and things should have the same intrinsic value regardless of the year in which they exist, even at any future time [42]. By including temporal equality in current research and development processes, due attention is given to all periods to come, including the possibility of an existence outside the Planet. By combining this approach with that of non-anthropocentrism, it is expected that sustainability and AI will be oriented not only to humans but will also include whatever is intrinsically valuable to them in the distant future. With this position, something similar to that of non-anthropocentrism happens, because, although it is consistent with general sustainability proposals, its emphasis is different. The reason is that these proposals do not involve precise time scales and, by not doing so, including from a few decades to an astronomically distant future, although in practice they are oriented to short-term issues. But this is another moral error since no valid justification is offered for the exclusion of generations, people, or anything else of intrinsic value in the distant future.

Likewise, attention should be drawn so that the effort in research and development in AI and sustainability is oriented to achieve the optimization of intrinsic long-term value; the reason is that a distant future offers great opportunities to promote this value, and those opportunities will be broader as the century progresses. In other words, the call is to prioritize AI with long-term sustainability and ethics, but without ignoring the present moment, because today's generation has special opportunities and means to develop ethical AI for the moment, which can, at the same time, engineer sustainable contributions for future scenarios and generations. If the goal is to realize the principle of long-term equality, a focus on long-term outcomes is also required; moreover, humanity must strive to promote moral progress in AI developments, including balanced sustainability.

In this order of ideas, we must also think in a long-term science, because the Planet will be uninhabitable in the future, either because of human actions, nature, or some astronomical issue [43], therefore, current science should already and is doing so, working on options to achieve that the survival of humanity is maintained in outer space. Undoubtedly, this goal will require a generation that is technologically advanced, prepared, and capable of surviving in that environment. With current developments and those to be achieved in the short and medium term, it is possible to achieve this goal, but human civilization must remain intact, i.e., that the actions and technologies of today do not become enemies of survival, which again calls attention to structure sustainable and ethical developments from AI.

Here it must be recognized that in many scientific and human contexts, a meaningful distinction between sustainability and temporal optimization for future generations is still not clear, and both goals require that the current generation enjoys sufficient resources and has security policies and actions to manage the threats to which it is exposed, such as global warming, pandemics, and possible nuclear war, which can spill over and weaken or spoil the continuity of humanity [44]. However, when analyzing the distant future today, both sustainability and optimization seem to point in different directions, because the general idea is that human survival in space only needs a minimal place, natural or artificial, to settle for very long-time scales. But it turns out that optimizing intrinsic long-term value requires first a large-scale conquest of space since the goal is to fill it with intrinsically valuable entities for human survival.

In these arguments, AI plays important roles: 1) current and near-term developments in AI can be used to address some of the immediate threats to humanity, such as global warming, famine, pandemics, and social alienation. Therefore, the sustainability of AI is paramount for the current generation and those to come, particularly as it can help sustain humanity far into the future. 2) Future developments in AI will be particularly important, especially when considering that it could be the last invention that man needs to create, provided it is smart enough to tell humanity how to keep itself under control [45]. So more attention will need to be paid to AI in the long term, given its potential importance for the long-term sustainability of humanity and the expansion of space.

In addition, there is also the dilemma of the duality of AI in the long term, since in current discussions it is seen as both a threat and an instrument for dealing with other threats. Hence the recommendation for the long-term development of AI is the sense of designing it judiciously and carefully so that it can be controlled and ensure high standards of security and ethics. But, on the other hand, if the development and deployment of long-term AI are delayed, its potential to address other threats may be reduced [44].

5. CONCLUSIONS

This chapter presents an examination of ethics, sustainability, and AI for human survival, and outlines arguments for adopting a long-term, non-anthropocentric conception of sustainability and optimizing it for the development of AI to support human and non-human survival off-planet.

It also provides recommendations on how AI should be developed to support the sustainability of future generations. All this through a work that specifies the ethical basis of what should be supported, as well as the time and effort needed to achieve long-term sustainability. Among these arguments is that the development of AI research and development must adopt the non-anthropocentric and long-term conception of ethical sustainability and optimization. In such a way that it becomes the basis for achieving the necessary resources for the current generation and for expanding future generations into outer space.

Another issue addressed in this chapter is related to the ethical principle of equality over time because a key aspect of sustainability is its projection into the future. This principle means that all subsequent moments must be approached equally, i.e., without prejudice against something just because it exists at one time or another. This requires AI and sustainability to pay attention to the distant future in which humans and non-humans will inhabit the universe, so they need to make an astronomically large positive difference today: to make space a better place for humanity's survival.

On the other hand, the systematic review of the literature found that the work on IA and sustainability is imprecise in its ethical dimensions, and only a few authors explicitly define sustainability. In the context of the environment, sustainability is seen as environmental protection or as an effort to regulate energy and resource consumption, although environmental problems do not necessarily have an implicit implication for sustainability. In other publications sustainability is related to good for humanity, stripping the term of the meaning given in this chapter.

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XIII
Innovate the context of education based on developments and discoveries in neurocomputing

Several developments and discoveries in neurocomputing related to cognitive development have been published in the last decade, and these findings could contribute to solving problems in the traditional education system. This work aims to review the state of the art on this topic. Studies in which these developments/discoveries were evident and experienced, while at the same time were assumed to be feasible for application during the formative processes of new generations, were selected and analyzed. The findings could determine that these emerging forms of neurocomputation, although designed to work according to the understanding of the brain derived from computational sciences, are still not completely aligned to improve human cognitive development. Therefore, future research should aim to take advantage of brain-inspired technologies and design educational tools geared towards the cognitive development of new generations, exploiting, for example, the research gaps found in this study.

1. INTRODUCTION

Within the last decade, the developments and discoveries of neurocomputing have become dominant content in multiple studies and research processes. Hence, topics such as machine learning, neural algorithms, and cognitive computing, based on the knowledge discovered from neurocomputing, are involved in online search engines, social media and social networks, and marketing [1]. Although these neurotechnological advances guarantee marked innovations in the brain-computer, cognitive training, and electronic neurostimulation interfaces for the coming decades, the education field cannot assume them yet as a lifeline for the innumerable and complex challenges regarding the cognitive development of the new generations [2].

Therefore, the education system cannot promote these digital technologies inspired by neurocomputing as components in the teaching models because research data only seem to show that they are efficient and effective for machine learning.

This task is not simple because, for these practices, models, and tools to be applied in a teaching model, new and different forms of analysis are required [3, 4]. Additionally, the implications for learning in the new generations must be analyzed because they have developed a different learning style [5] than that which the education system considers established for the whole world. For example, although the developments and discoveries of neurocomputing are understood as biosocial technologies, according to the current neuroscientific idea that children's brains show high plasticity, these same advancements could work in education. The biological understanding of this plasticity still does not offer solid foundations to establish a line of action [6].

In addition, the vision of learning from neurocomputation has been rarely investigated in educational research, especially in post-human, computational, or algorithmic life and the realms of the human or inhuman [7], where biological life and computational sciences are superimposed [8]. Studies in this field propose that the practical or mechanical aspects of neurocomputing should not be automatically assimilated as direct sources for human learning, but as referents, with profound, wide, and complex ethical implications that can potentially modify aspects from the very systems from which they emerged [4].

Therefore, Weinstein and Colebrook [9] affirmed that advances in life and the biological and computational sciences will not only require a critical rethinking of the residual historical images of biology and education, but they may also demand new concepts and thoughts about life to understand the human being before these advancements can be included in educational practice [10-12].

One of these complex problematic referents revolves around determining the role of education in today's society to establish whether technological changes influence the learning of current and future generations [13]. These authors explored how new technologies can be involved in education, particularly how neurocomputation and brain-based developments are used as biosocial technologies to design educational models, based on discoveries about the brain's plasticity, in such a way that this brain understanding is oriented to develop programmed learning.

This is not simply about adapting ideas from one field of research to another but about verifying and validating whether knowledge, developments, and discoveries can be used in educational research. This incorporates aspects of biotechnology [14] to show how data and discoveries from neurocomputation can be used to further develop the teaching models, that at the same time can be reoriented to meet the demands and expectations of the new generations during their formative process. Although these ideas may be utopian, the goal should be to create a teaching model adapted to the qualities of students of today and tomorrow. Educational research still does not pay much attention to this concept, even though the notion that the future is here and now has existed since the beginning of the century, but the education system has not yet noticed it [15].

In addition, although these innovative practices and environments generated by neurocomputational research could interrelate the social, biological, and computational components of learning, the first aspect that should be critically analyzed is their contributions to educational research. This work, generated from a research program whose objective is to determine the existence of a learning algorithm in the new generations, provides an analysis of the developments/discoveries of neurocomputing related in some way to learning. It is a structured review of the literature published in the last decade in which these contributions are evidenced and experienced, while at the same time presumed to be feasible for application during the training processes of new generations.

The findings could determine that these forms emerging from neurocomputation, although designed to work according to the understanding of the brain derived from computer science, still do not fully align to improve human cognitive development. Therefore, several authors present an interesting idea in which the brain/code/space is viewed as a technologically mediated conceptual framework. In the end, the challenge is to design teaching environments in which learning and cognition can be potentiated through processes that work in neurocomputational research. In addition, future research in this field should be oriented to take advantage of the brain-inspired technologies, developed by neurocomputational scientists, in such a way that researchers in education can design educational tools to optimize cognitive development in new generations.

2. METHOD

To carry out this systematic review of the literature, the authors adapted the practical guide by Petticrew and Roberts [16], which is considered a systematic review process whose objective is to reduce bias, test a hypothesis, and answer specific research questions. An adaptation of the guide is presented below.

- *Step 1*. Define the research question. The objective of this study is to identify and analyze the developments/discoveries in neurocomputing related to learning and published within the last decade. Therefore, the research team formulated the following research questions: 1) what developments/discoveries have been published in the last decade that define the neurocomputing-learning relationship? and 2) is any integration with educational theories proposed to improve the cognitive processes?

- *Step 2*. Gather a team of advisors. The guide suggests assembling an interdisciplinary group of specialists to analyze the field under study from different perspectives. In this case, the team consisted of researchers who work in the field of educational innovation and computer science with experience in the analysis of teaching-learning models; an advisor from the University of New York with research and experience in cognitive neuroscience; and an MIT consultant who researches and analyzes the relationship among computational sciences, artificial intelligence, and human learning. The thematic contributions from each of these disciplines provided solidity to the analyses and results presented in this work.

- *Step 3*. Perform the literature search and select references. The team decided to select databases in which works related to development and discoveries in neurocomputation and learning were published. The search process was carried out in the following databases: IEEE Explorer, ACM Digital Library, ScienceDirect, Springer Journal, and Taylor & Francis. The main keyword used in the searches was Neurocomputation in combination with the following terms: learning, learning analysis, new generations, learning style, teaching model, educational theories, and cognitive development. The goal was to identify relevant papers in the search results from these combinations.

- *Step 4*. Evaluate the results according to the inclusion/exclusion criteria. The search was carried out between January and August of 2022. This was decided based on the fact that the appearance of structured contributions in the research topics related to learning in the new generations showed an important boom from the beginning of the new century, but the results appeared at the end of the first decade. The inclusion and exclusion criteria defined for the review are shown in Table 1.

Table 1. Inclusion/exclusion criteria

Inclusion criteria	**Exclusion criteria**
Works that describe results in at least one of the established combinations	Poster, because its scope is often limited and lacks details that can lead to biases in the study
Published between 2008 and 2022	Works in which the sense of the application of the main word is oriented only to machine learning
Documents describing visualizations as part of a solution or intervention	Documents in which the analysis component is not included in the results
Research describing the methodology applied and the validation of results	Previous reviews in which the lifeline is outside that established in this study

- *Step 5*. Critical analysis and data extraction. According to the research questions defined, the analysis was structured into two phases: 1) identify approaches, purposes, contexts, and validations of the developments/discoveries and the connections between the categories defined in the search combinations; and 2) determine the method by which the authors propose the assimilation of their findings into educational processes.

1. *Phase one*. The objective was to identify developments/discoveries that are published about neurocomputing and learning and in which analysis and validation of results and projection of use are integrated. Therefore, the research context, the educational context of the application, the validation structure and strategy, the type of development/discovery, and the initial purpose of the study were analyzed. Likewise, the volume of publications identified among the different combinations was compared to identify possible relationships between the searches.

2. *Phase two*. Different approaches and challenges were observed when analyzing the integration of the findings and the educational process [17, 18]. This process is complex and incorporates several components that should be considered, such as team interaction, student interest, teaching models, learning styles, and teaching tools. In addition, in certain teaching-learning scenarios, some components may work better than others [19]. Therefore, caution is advised with results that are obtained based on scores awarded in unstructured validation processes because they can generate deviations in the analysis.

For this work, the interests of the researchers focused on identifying how developments/discoveries are integrated with educational theories. In addition, the analytical systems of achievement were validated by educational theories and practices so that teachers and students can use them to enrich their teaching-learning models [20-22]. Therefore, aiming to characterize the results of the review, the team decided to adapt the assessment system based on three dimensions (Table 2) proposed by Vieira and his colleagues [23].

Table 2. A valuation system used to characterize the works

Dimension	Assessment			
	1-2	3-5	6-8	9-10
1. Connection with the existing educational stock	Does not connect prior educational theories, guidelines, or principles	Mentions, without discussion, any theory, guideline, educational principle, or analysis of the findings using any existing literature	Discusses relevant literature in the area and/or integrates educational theories, guidelines, or principles, and/or discusses the findings using prior literature	Critically analyzes the relevant literature and makes informed decisions to perform the integration and analyzes the findings using recent literature
2. Link with educational theories	Does not link to any educational theory	Briefly describes some educational theory without integrating it into the work or discussing the results based on that theory	Involves in the discussion or uses some educational theory or discusses the results based on that theory	Addresses the critical analysis of an educational theory, integrates it with the findings, and analyzes the results based on the theory
3. Total relationship with educational theories	Not related to any educational theory	Involves one or two multiple, connected, multilevel, interactive, or novel educational theories	Includes three or four multiple, connected, multilevel, interactive, or novel educational theories	The integrated educational theory is multiple, connected, multilevel, interactive, and novel

For the first two dimensions, the full integration of the development/discovery in neurocomputing with the existing educational theories was considered to understand the critical analysis of the integration, the accuracy of the connection, and the analysis and discussion of the findings in the light of educational theory. For the third dimension, proposals were considered in which a level of consensus on the effectiveness of integration was identified. It is expected that, in the results reported and defined as tools that can be integrated into educational processes, it is evident that the findings can be validated from the point of view of educational theories.

Therefore, for this dimension, the following factors were considered in the scoring process: 1) whether one or several theories were used, 2) whether these theories were interconnected, 3) whether the integration allowed multilevel analysis, 4) whether the integration was interactive, immersive and in real-time, and 5) whether the tool used was novel. In any case, the objective of the evaluation was not to measure the quality of the work but to find elements to carry out an effective analysis of the contribution to the research in which it is framed, thus, it is easier to identify gaps in the state of the art and propose research processes that contribute to the development of the area.

This is based on the hypothesis posed by the research team regarding two lines of independent development in the integration of neurocomputing and educational processes. On the one hand, neurocomputational scientists develop sophisticated processes and can provide information for educational theories, although there is no evidence of deep interaction with them to channel their discoveries and expand the body of knowledge.

On the other hand, researchers in education explore educational theories and phenomena, but their processes are often simply those used by scientists. This hypothesis is supported by the contributions of various authors who advocate greater integration between both universes, such as Dawson et al. [24], Lockyer et al. [25], and Gašević et al. [26].

In addition, to carry out a comparative analysis of the reliability of the selected sample, the team randomly distributed the works to qualify them independently. They met several times to analyze the ratings provided and during disagreements, the individual analyses were evaluated until the team reached a consensus. When no agreement was reached, the valuation system was refined, and additional rounds of evaluation were carried out for reliability.

3. RESULTS

The search yielded an initial sample of 118 works, which were examined by applying the criteria described in Table 1. The result was a final sample of 48 documents that met the criteria of the research methodology and that provided a basis for answering the questions formulated in the study.

3.1 Developments/discoveries that relate neurocomputation-learning

To define this finding, the research context, the educational context of the proposed application, the structure and validation strategy, the type of development/discovery, and the initial purpose of the research were analyzed. Likewise, the volume of publications among the different combinations was compared to identify possible relationships among the combinations. All selected works were reviewed to identify the characteristics of the first phase of research.

- Five contexts of research development were identified:

  1. *Mental representations*: Ludwig and Schneider [27], Ludvig et al. [28], Horst [29], Knott [30], Mandik [31], Goel and Rugaber [32], Williamson [33], Twomey and Westermann [34].

  2. *Knowledge-based on neurocomputing*: Kolman and Margaliot [35], Asghari and Hu [36]; Band [37], Pona [38], Tripathi [39], Guo et al. [40], Falotico et al. [41], and van Rossum [42].

  3. *Cognitive computing*: Wang [43], Cattinelli [44], Boqvist [18], Rhodes [45], Daw [46], Varshney et al. [47], XiaoLan et al. [48], Garrett [49], Lockwooda et al. [19], Gliozzo et al. [50], Huber [51], van Wyk [52], Chen et al. [53], and Williamson et al. [13].

  4. *Computational research studies in neuroscience*: Fan et al. [54], Shagrir [55], Ermentrout and Terman [56], Wiecki and Frank [57], Maia and McClelland [58], Crook et al. [59], Lytton and Kerr [60], Rescorla [61], Williamson [62], Lawrence [63], Ahn et al. [64], and Ahmad et al. [65].

  5. *Cognitive algorithm*: Gallistel and King [66], Modha et al. [67], Boyce and Hancock [68], Eliasmith [69], Piccinini and Bahar [70], and Anderson [71].

- It was discovered that some of these developments/discoveries can be projected in diverse multidimensional educational contexts, such as: 1) the traditional school [44, 66]; 2) ubiquitous environments [19, 30, 67; 3) virtual education [18, 41, 53]; and 4) learning based on challenges [43, 52, 61].

- Regarding the structure and strategy to validate these developments/discoveries, some traditional methods were identified, such as the comparative analysis with results in similar research [27, 61]. Some innovative approaches were also used, such as validation by pairs [19, 47], informed experimentation [29, 34], computational simulation [18, 44, 57, 58], and artificial intelligence as a neurocomputational framework [35, 41].

- The classification of the type of development/discovery was conducted based on the authors' descriptions, but when it could not be identified directly, a comparative analysis of the author's trajectory and previous contributions was used. As a result, the following types were identified:

  1. *Models*: Ludwig and Schneider [27], Ludvig et al. [28], Horst [29], Daw [46], Mandik [31], XiaoLan et al. [48], Anderson [71], Knott [30], Goel and Rugaber [32], Williamson [62], and Twomey and Westermann [34].

  2. *Work or application frameworks*: Kolman and Margaliot [35], Boqvist [18], Maia and McClelland [58], Garrett [49], and Tripathi [39].

  3. *Neural networks*: Kolman and Margaliot [35], Asghari and Hu [36], Band [37], Pona [38], Guo et al. [40], Falotico et al. [41], van Rossum [42], and Gliozzo et al. [50].

  4. *Theoretical*: Gallistel and King [66], Ludvig et al. [28], Asghari and Hu [36], Crook et al. [59], Band [37], and Goel and Rugaber [32].

  5. *Algorithmic*: Gallistel and King [66], Modha et al. [67], Boyce and Hancock [68], Eliasmith [69], Piccinini and Bahar [70], Anderson [71], and Williamson [62].

- For the research team, it is important to determine the initial purpose of the research to transmit the results and determine the usefulness of a learning algorithm for new generations. Therefore, it was relevant to identify studies whose initial objective was to work in the search, definition, structuring, or demonstration of programmed learning. In the analysis of the results, it was found that 38% of the investigations were framed in this context, including 19% for theoretical contributions, 23% to determine mental representations of learning, and the remaining 20% to perform studies of the relationship between neuroscience and neurocomputation.

3.2 Integration of Developments/discoveries with Educational Theories

The second research question aimed to identify the integration of these developments/discoveries with educational theories. The analysis consisted of identifying the relationship between each work and educational theories and assessing this relationship from the dimensions described in Table 2. The results showed that although there was at least one study with a high valuation in some of the dimensions (between 9 and 10), it was not possible to find works that were equally valued in all dimensions.

To perform an analysis with a sense of projection of the utility of the contribution, the team decided to triangulate the information regarding the type of development/discovery with the dimensions defined in Table 2, averaging the assessment of the relationship identified in each one with the educational theories. The results are shown in Figure 1.

Figure 1 shows that the theoretical type presents a higher average rating than the others, whereas the lowest rating was provided by the type of neural network. From the point of view of the investigative process used in this study, it is positive that the algorithmic type obtained an average assessment of 3-4 in the dimensions because they provide a basis to continue demonstrating the hypothesis that the students of the new generation have developed an algorithm in their learning styles. In this sense, these developments/discoveries could be used to experiment with student groups in field work within continued research.

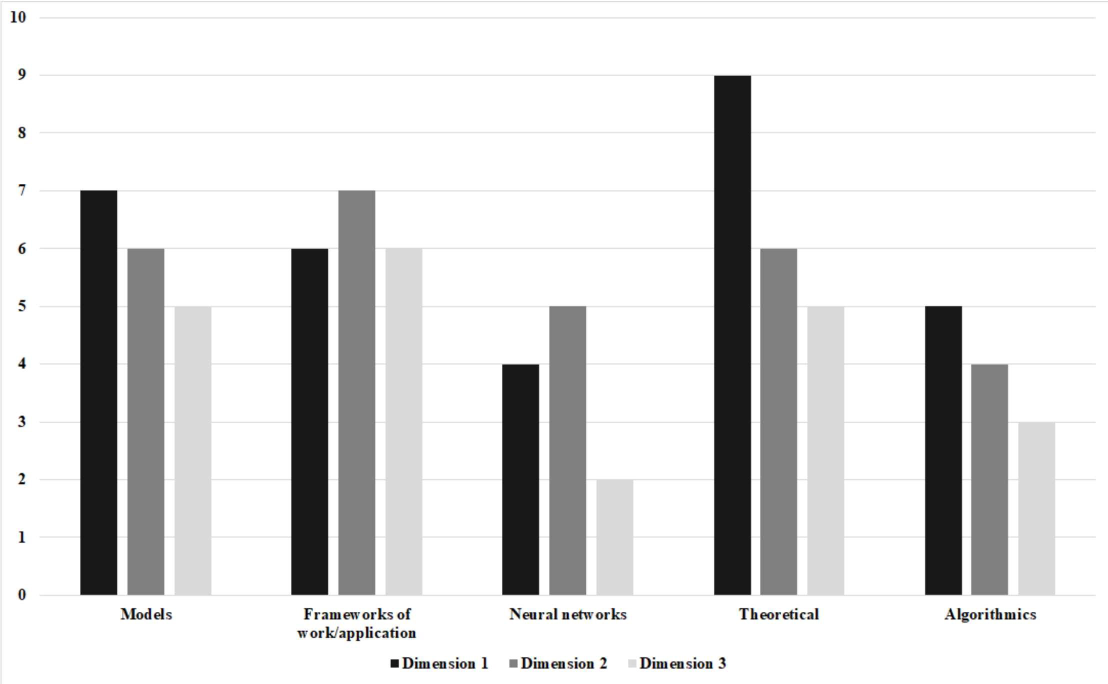

Figure 1. Average rating of the integration of the types of developments/discoveries with educational theories

In any case, these results must be integrated into those obtained by the additional members of the work team whose objective was to analyze these same relationships from the perspective of neuroscience and psychology. Table 3 shows the works according to the average assessment obtained in terms of their integration with educational theories from the dimensions proposed in the methodology.

Table 3. Evaluation of the works in the established dimensions

Dimension	Works			
	1-2	3-5	6-8	9-10
1	[29-31, 41, 62]	[18, 28, 42, 59, 66, 71]	[27, 32, 33]	[66]
2	[38, 39, 46, 48, 70]	[35, 37, 40, 67, 71]	[28]	
3	[34, 36, 37, 58, 69]	[32, 36, 49, 50, 68]		

4. DISCUSSION

Although the final sample of the review in the first phase consisted of 48 papers in which developments or discoveries in neurocomputing were described and a certain relationship with cognitive development was mentioned, only in three studies could a description of use or experimentation be identified in this sense: Gliozzo et al. [50], Falotico et al. [41] and Ahn et al. [64]. Said finding was expected because the work of neurocomputational scientists presents, in most cases, a different approach to that of researchers in education.

However, it reflects an opportunity for the latter to explore the use of developments/discoveries in neurocomputing in their research contexts, plus the advantage of having greater control in their experimental environments than in a laboratory.

In addition, the demographic data that supports each development/discovery is easier to collect and analyze for educational researchers because they can rely on the contributions of students and the information derived from ubiquitous interactions. This approach can isolate information from variables that could be relevant to laboratory work but not to classroom activities. An additional advantage for researchers in education is that they have visual dominion of the experimentation for the analysis of results and can operate with multiple data sources, an opportunity that could be exploited when working on cognitive development [72].

Lockyer et al. [25] stated that the analysis and validation of the integration of any development to the educational processes can be oriented from analysis to the control points and/or from analysis to the process in its entirety. The first involves the use of developments/discoveries in a learning environment, whereas the second refers to the actions that people could take to complete a learning task using those contributions. The analysis of the results of this research showed that most authors (81%) apply the analysis to the entire process.

Although both approaches are useful in study environments, researchers in education obtain more information when applying the analysis of control points because the nature of their work is oriented to on-site validation. On the contrary, for neurocomputational scientists, it is more relevant to analyze the entire process. Their objective is to validate the results through projections and computer simulations because they can use non-invasive data to go beyond the product they hope to develop.

Another finding of this research is that the developments/discoveries in neurocomputation related to learning use specific analysis tools for neurocomputational scientists and not as much for researchers in education. This finding is understandable according to the selected sample because multiple authors work in collaborative environments with other scientists and need to establish a common communication framework. However, researchers in education can take advantage of their tools, including their former experience, to validate the integration of developments/discoveries in learning processes.

In this sense, they obtain different information that could be exchanged with neurocomputational scientists to integrate it into their validations. This exchange process would enrich the research area and contribute to closing the different gaps that exist in their fields, thus providing another opportunity for collaborative work to integrate the results from both sides. This work must be developed cautiously to avoid the phenomenon of validation negatively impacting the motivation of the subjects in the learning environment because working with machines is very different from working with humans.

On the other hand, researchers in education expect that developments/discoveries in neurocomputing will allow them to innovate teaching models for expanded education while at the same time potentiating the characteristics of environments such as ubiquitous learning and challenge-based learning. However, according to the works analyzed in this study, the work strategies and research objectives of neurocomputational scientists in this field are still far from satisfactory.

Their techniques are specific, and their goals are general; namely, they still do not foresee a contribution exclusively to cognitive development. Some of these contributions are oriented to help correct brain problems, whereas others are intended to remedy specific brain diseases. Therefore, their contributions do not meet the needs of the researcher in education.

Regarding the second phase of this research, which aimed to find how developments/discoveries in neurocomputing are integrated with educational processes, the existence of gaps between the work of neurocomputational scientists and researchers in education was determined. Note that in Figure 1, there are some studies evaluated with high scores in some of the dimensions of Table 2. However, none presented the same scores in all the dimensions. In general, the developments/discoveries of algorithmic types and those of neural networks showed the lowest scores in all dimensions because these works aimed to identify principles and theories with applications in artificial intelligence [11].

The studies by Ludwig and Schneider [27], Goel and Rugaber [32], Williamson [33], Ludvig et al. [28], and Gallistel and King [66] were the best evaluated in the analysis because they include elements that the integration of the characteristics of the dimensions was evident. These studies discussed relevant literature in education, integrated educational principles, discussed results based on some educational theory, or analyzed the findings using recent literature in education. However, none involved multiple educational theories or presented a critical analysis of any theories. Therefore, a research gap is evident here, and this gap should be addressed by education researchers. Figure 2 shows the distribution of the assessment of the works about their integration into the defined dimensions.

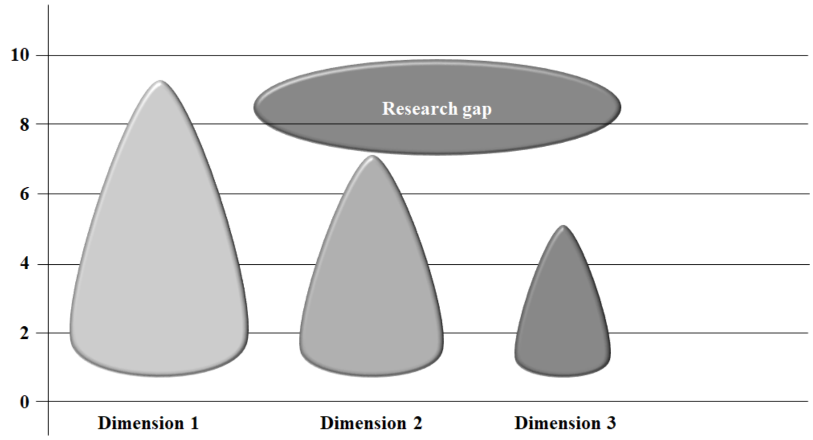

Figure 2. Distribution of the valuations among the dimensions

In this case, the research gap could be addressed by researchers in education working with neurocomputing scientists and taking advantage of the results that each one has validated separately. The results of this integration could yield more encouraging derivations on the integration of the developments/discoveries in neurocomputing with the cognitive processes in such a way that they contribute to innovating the processes and educational theories to benefit the education system.

5. CONCLUSIONS

The relationship between neurocomputing and cognitive development is a field of research that emerges as an opportunity to integrate the work of neurocomputational scientists and researchers in education, providing ideas and experiments in which large amounts of data are shared.

This study presents the results of a review of the literature whose objectives were as follows: 1) to identify the developments/discoveries published in the last decade that define some relationship between neurocomputing and learning, and 2) to determine if these developments/discoveries propose any integration with educational theories.

The main limitation of this research is inherent to any structured review of the literature, namely, the delimitation of the research sources because the selection of the works for the sample may bias the findings of the study. Although the databases selected in this study are relevant and are recognized for publishing works in the areas defined in the research, they may be flawed because they are multidisciplinary. This could be reflected in the lack of deeper evaluations involving the results published in the neurocomputing-learning relationship of the works. However, one of the strengths of the study was the inclusion of external thematic advisory in the specific areas, which offers credibility and impartiality in the analyses and evaluations.

For the research team, these results became the primary source for continuing to develop the research process to validate or deny the existence of a learning algorithm in new generations. Therefore, it is expected that the identification of gaps in the investigation of the neurocomputing-learning relationship will motivate educational researchers to establish alliances with neurocomputational scientists and to initiate interdisciplinary work at the intersection of machine learning and human learning to foster new developments and innovations in methodologies, didactics, and curricula to meet the demands and needs of new generations.

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XIV

Analysis of the effectiveness of teaching-learning models for mathematics training in the 21st century

This chapter presents the result of a study whose objective is to determine the effectiveness of teaching-learning models for mathematics training in the 21st century. Using an analysis of the results of the case studies found in the literature and applying the method of triangulation of variables, the Kirkpatrick evaluation model was used to determine effectiveness. The results show that of the 13 teaching-learning models analyzed, only two are located at level 4 (*Excellent*) and three at level 3 (*Good*), which allows us to conclude that they still do not achieve the effectiveness necessary for the students to be adequately trained in mathematics to respond to social demands. Among the causes are teachers without professional experience, outdated curricula, disciplinary work, practices, and didactic that do not motivate, and memorization-based evaluation, among others.

1. INTRODUCTION

The ultimate goal of any teaching-learning model is to develop or improve capacities, abilities, and skills in students so that they can apply them to perform the tasks and functions associated with the training received. Therefore, evaluating the effectiveness of a model consists of an analysis of the value of what the student has learned in cultural, social, and application terms. In addition, more than the achievement of objectives, the cost-benefit for the student must be estimated after experiencing the model. This implies that the level at which this achievement meets the initial needs of the student must be determined, evidencing in qualitative and quantitative terms the change between the initial reality and the final reality [1].

In this case, the effectiveness of the model is analyzed from the *training perspective*, in terms of achieving objectives, from the *social perspective*, in terms of the use of learning, from the *cultural perspective*, in terms of improving the cultural stratum, and from the *economic perspective*, regarding the cost-benefit ratio.

When analyzing the effectiveness of models related to teaching and learning, we must take into account that the education system, of which they are a part is composed of different systems and dimensions, such as students, teachers, curriculum, administrators, contents, technology, and physical and financial resources. Among them, *teachers*, *students*, *didactics,* and *content* are the basic elements to structure the analysis. This is because, in the teaching-learning models, these components of the system are those that directly affect teaching effectiveness.

Among the most important characteristics of the teachers are the planning of the activities; their discipline, motivation, training, and experience; and the selection of the didactics. For students, the most important characteristics are their socioeconomic context, behavior, personal characteristics, cultural stratum, predisposition, generation, and level of motivation. In the didactics, the focus is given to their updating, use of technologies, ease of use, familiarity for the student, and theoretical-practical level. Finally, for the contents, the characteristics to be taken into account are being up-to-date, theory-practice relationship, bibliographic basis, linkage with other courses and with the career, and importance for the student's training.

However, because the objective of this study is to determine the effectiveness of teaching-learning models about training in mathematics, it is also taken into account that, as a training area, training in mathematics has multidimensional variables that relate it to various disciplines. In addition, when triangulating these variables and models, it is expected that the elements involved achieve the objective of transferring mathematical knowledge, which the student needs to develop the skills, abilities, and capacities that allow them to adapt to the context and integrate them with the knowledge acquired in other courses to continue his or her training [2]. Likewise, and by tradition, mathematics provides the basis to satisfy the basic needs of societies because, while knowledge progresses in them, so does the development of technology, science, and engineering [3].

It is expected that the curricula of mathematics, in continuous relation with the other elements, will satisfy the expectations and needs of the students in their desire to obtain an academic degree. Therefore, it is expected that at the end of the course and after working with the teaching-learning model defined by the teacher, students will develop mathematical skills, logical thinking processes, and abstraction skills, which they will subsequently strengthen and use to solve social problems as they improve their capacities and life plan. Then, mathematics courses should involve more than simply reasons for students to learn concepts; they must convince students of the courses' importance through the multidimensional and transdisciplinary relationship with other courses, development, and challenges students will encounter in their work life. This is because mathematics is a way of thinking that all professionals need to develop to different degrees, although it is traditionally thought that it is only useful for science and engineering disciplines [4].

It is also important to analyze the selection of teaching methods and the teaching model that teachers apply because they are indicators of their training and ability to meet the needs and demands of students concerning mathematics courses. In this sense, some authors recommend that teachers should periodically perform a self-assessment of their strengths and weaknesses, in terms of teaching, content, and understanding of the new generations of students because in this way they can find and determine their preferences and thus select a teaching model [5]. The argument is that, as teachers better understand students and the classroom context, they improve their training and develop new teaching skills. In addition, they gain a broader understanding of the curriculum and can help students integrate mathematical knowledge with other courses.

In this process, teachers need to recognize the natural interest of new generations in mathematics and the intuitive and informal knowledge they have acquired through their skills using and understanding technology. These characteristics challenge students to investigate and explore ways to solve problems while developing logical-mathematical reasoning. This leads students to accept mathematics as an object of study because mathematics is shown to be useful as a common tool and, by using it, students develop their mental schemas to understand the world. This is where differences arise between those who understand mathematics and those who have difficulties understanding it because mathematics is not only memorizing or learning for an exam, but it is also creating an environment in which the student perceives the importance of this area, applies it and obtains satisfying benefits and results [6].

The achievement of this objective depends to a large extent on the teaching-learning model selected by the teacher and the student. Therefore, it is important to analyze the effectiveness of these models to achieve the objective that students assimilate, use, and diversify mathematical knowledge. This chapter presents the results of an investigation in which this effectiveness is analyzed. A literature search was conducted to find the case studies that present results from analyzing the models used in the classroom and using triangulation and mixed analysis techniques, valuation metrics were applied to rank the models by the level of effectiveness.

2. METHOD

In this study, a descriptive study was carried out to find in the literature the teaching-learning models and the results that are reported in the case studies about their application. A descriptive model was used to analyze specific situations at specific times, seeking to understand the start and end states through the modifications that certain characteristics have undergone.

The data for the analysis were collected from the case studies published about the teaching-learning models in mathematics training in the 21st century, through a mixed research method [7]. According to some authors, this methodology allows researchers to find answers to questions such as what, why, and how by examining in detail the results of specific cases [8].

Therefore, in the methodology of the present investigation, mixed techniques were applied for data collection, such as the literature review and the analysis of documents, and the results were analyzed by triangulation to reveal their level of accuracy and integration. Case studies help to understand specific situations and analyze results because they involve a situated nature and describe the complexity of the variables involved. In this sense, they have the potential to specify concepts of study and contribute to their understanding, which is why they are usually used to show results of comparison and evaluation of situations at defining moments.

The central theme of this study is the teaching-learning models reported in the case studies in the literature, whose results were analyzed in terms of the effectiveness of the training in mathematics. A search was carried out using a structured protocol [9] agreed upon by the researchers, and subsequently, an analysis was made by triangulation of the variables involved. After defining the usefulness of the studies, the information reported was validated using verification of the methodology and the applied equations. In the studies, the following data were verified: 1) characteristics of the document: year, medium, type, thematic relation, and relevance; 2) characteristics of the author: experience in the area and citations; 3) results: clarity and replicability, and 4) applied methodology.

3. RESULTS

3.1 Review of the Literature

Based on the application of the methodology, 39 studies were found in which results are presented of the experimentation of the teaching-learning models for mathematics training in the 21st century. Table 1 shows the works selected for the analysis, triangulation, and assessment of the effectiveness of the models.

Table 1. Selected works for analysis

Year	Work
2002	▪ Ashcraft M. Math anxiety: Personal, educational, and cognitive consequences. Current Directions in Psychological Science 11(5), 181–85. ▪ Houssart J. Simplification, and repetition of mathematical tasks: A recipe for success or failure? The Journal of Mathematical Behavior 21(2), 191–202.
2003	▪ Arcavi A. The role of visual representations in the learning of mathematics. Educational Studies in Mathematics 52(3), 215–41. ▪ Furner J. and Berman. B. Math anxiety: Overcoming a major obstacle to the improvement of student math performance. Children Education 79, 1–6.
2004	▪ Fernandez C. y Yoshida M. Lesson Study: A Japanese Approach to Improving Mathematics Teaching and Learning. Erlbaum.
2005	▪ Barkatsas A. and Malone J. A Typology of mathematics teachers' beliefs about teaching and learning mathematics and instructional practices. Mathematics Education Research Journal 17(2), 69–90. ▪ Hill H. et at. Effects of teachers' mathematical knowledge for teaching on student achievement. American Educational Research Journal 42(2), 371–406.
2006	▪ Anghileri J. Scaffolding practices that enhance mathematics learning. J. of Mathematics Teacher Education 9, 33–52. ▪ Boaler J. How a detracked mathematics approach promoted respect, responsibility, and high achievement. Theory into Practice 45(1), 40–46. ▪ Burris C. et al. Accelerating mathematics achievement using heterogeneous grouping. American Educational Research Journal 43(1), 137–54. ▪ Sullivan P. et al. Teacher actions to maximize mathematics learning opportunities in heterogeneous classrooms. International Journal of Science and Mathematics Education 4(1), 117–143.
2007	▪ Anthony G. and Walshaw M. Effective pedagogy in mathematics/pangarau: Best evidence synthesis iteration [BES]. Ministry of Education. ▪ David J. and Greene D. Improving mathematics instruction in Los Angeles high schools: An evaluation of the PRISMA pilot program. Bay Area Research Group. ▪ Flores A. Examining disparities in mathematics education: Achievement gap or opportunity gap? High School Journal 91(1), 29–42. ▪ Hiebert J. and Grouws D. The effects of classroom mathematics teaching on students' learning. In Fliord L. (ed.), Second Handbook of Research on Mathematics Teaching and Learning (pp. 371–404). Information Age. ▪ Martin T. Mathematics teaching today: Improving practice, improving student learning. National Council of Teachers of Mathematics.
2008	▪ Boaler J. and Staples M. Creating mathematical futures through an equitable teaching approach: The case of Railside school. Teachers College Record 110(3), 608–45. ▪ Thomas M. and Chinnappan M. Teaching and learning with technology: Realising the potential. In Humbert F. (ed.), Research in Mathematics Education in Australasia (pp. 2004–2007). Sense Publishers.

	▪ Tripath P. Developing mathematical understanding through multiple representations. Mathematics Teaching in the Middle School 13(8), 438–445. ▪ Zevenbergen R. and Lerman S. Learning environments using interactive whiteboards: New learning spaces or reproduction of old technologies. Mathematics Education Research Journal 20(1), 107–125.
2009	▪ Cai J. et al. Effective mathematics teaching from teachers' perspectives – national and cross-national studies. Sense. ▪ Hull T. et al. A guide to mathematics coaching: Processes for increasing student achievement. Corwin. ▪ MSRI. Teaching teachers' mathematics: Research, ideas, projects, evaluation. In Cathy K. (ed.), Critical issues in mathematics education. Mathematical Sciences Research Institute. ▪ Seeley C. Faster isn't smarter: Messages about math, teaching, and learning in the 21st century. Math Solutions. ▪ Stein M. et al. Implementing standards-based mathematics instruction: A casebook for professional development. Teachers College Press.
2010	▪ Garet M. et al. Middle school mathematics professional development impact study: Findings after the first year of implementation. National Center for Education Evaluation. ▪ Kapur M. Productive failure in mathematical problem solving. Instructional Science 38(6), 523–50. ▪ Yelland N. and Kildery A. Becoming numerate with information and communications technologies in the twenty-first century. International Journal of Early Years Education 18, 91–106.
2011	▪ Boaler J. Changing students' lives through the de-tracking of urban mathematics classrooms. Journal of Urban Mathematics Education 4(1), 7–14. ▪ Campbell P. and Malkus N. The impact of elementary mathematics coaches on student achievement. Elementary School Journal 111(3), 430–54. ▪ Cohen J. and Hollebrands K. Technology tools to support mathematics teaching. In Tony D. and Kevin H. (eds.), Focus in High School Mathematics: Technology to Support Reasoning and Sense Making (pp. 105–22). National Council of Teachers of Mathematics. ▪ Middleton J. and Jansen A. Motivation matters and interest counts: fostering engagement in mathematics. National Council of Teachers of Mathematics. ▪ Smith M. and Stein M. 5 practices for orchestrating productive mathematics discussions. National Council of Teachers of Mathematics. ▪ Sullivan P. Teaching mathematics: Using research-informed strategies. Acer Press.
2012	▪ Wager A. Incorporating out-of-school mathematics: From cultural context to embedded practice. Journal of Mathematics Teacher Education 15(1), 9–23.
2013	▪ Battey D. Good mathematics teaching for students of color and those in poverty: The importance of relational interactions within instruction. Educational Studies in Mathematics 82(1), 125–44. ▪ Berry R. and Ellis M. Multidimensional teaching. Mathematics Teaching in the Middle School 19(3), 172–78.
2014	▪ Clark C. et al. Gaining control: Changing relations between executive control and processing speed and their relevance for mathematics achievement over course of the preschool period. Frontiers of Psychology 5, 107-118. ▪ Haase V. et al. Contributions from specific and general factors to unique deficits: Two cases of mathematics learning difficulties. Frontiers of Psychology 5, 102-113.

3.2 Practices and didactics for training in mathematics

In this chapter, *practice* is taken as the continuous and regulated activities used by teachers in the classroom to develop students' mathematical skills and abilities. For their part, *didactics* are the teaching techniques and methods teachers select to carry out these activities. However, because the education system is influenced by social, technological, and scientific revolutions, its use suffers alterations, although didactics are traditionally characteristic of education. Since ancient times, models, practices, and didactics have been used in teaching [10]. Therefore, in one way or another, they were also used in mathematics.

More than a century ago, Modjeski et al. [11] investigated this issue and found that mathematics was for the engineer and anatomy was for the surgeon or training for soldiers. To the question: *What is needed to teach mathematics in engineering?* they answered: 1) teaching a varied, but limited, range of subjects, 2) covering these subjects with different degrees of depth, 3) using mixed presentation practices, and 4) having precise teaching-learning goals. This is because, as the authors concluded, many of the topics taught are useless in practice. These observations of the early twentieth century seem not to have gone out of style because they are still currently experienced in the classroom.

Later, Wigley [12] claimed that in the teaching exercise, there was a tendency to polarize the practices and didactics of teaching-learning of mathematics in the instructive and exploratory fields, although the reality showed that because of the diversity of students in the classroom, it was best to use a mixture of several models. For this author, the problem was not how to achieve that combination but how to handle the creative tension that lies between instruction and exploration, to decide what, when, how, why, for what, and where to teach mathematics. In the same sense, OECD [5] emphasized the need to redirect practices and didactics in the teaching of mathematics, arguing that professionals at that time did not work as their colleagues 50 years ago; it also stated that the development of automatic calculation techniques should be taken into account.

At the end of the twentieth century, Larcombe [13] stated that mathematics could not be taught with practices and didactics taken from a recipe book, that the rigor that teachers placed on these courses made them undesirable for students, and, among other things, that the contents, although they were important, did not give students the training they needed in their professional life.

For his part, Prince [14] showed that, in the learning of mathematics, better results are obtained when students are invited to participate actively in the design of practices and didactics. This participation should include a collaborative approach, for example, in co-assessment and peer tutoring [15] or course design [16, 17]. For Booth [18], since the end of the last century, students and a large part of society and industry have been insisting on the need to change what and how mathematics is taught.

One of the repeated requests is that it should be taught by teachers with professional experience because they know how to integrate it into each discipline and know the contents that should be taught. Along the same line, other researchers have requested urgent changes in practices and didactics, arguing, among other things, that mathematicians do not have the practical experience necessary to teach because, generally, they are theoreticians [4, 19-22].

For Kidwell et al. [23], current teachers use tools designed a long time ago. They make the distinction between physical (technological) and conceptual (methods, ideas, models) tools and conclude that it is difficult to find one of the two with greater application and acceptance because what is dynamic in the teaching process is the students, who do not allow either to dominate. The class notes that survive history show what they have done and what their vision is about the practices and didactics that teachers used when teaching mathematics [24].

To achieve meaningful learning in mathematics, Ikeda [25] recommends considering and contrasting the internal and external contexts of the school, from which the practices and didactics that allow achieving learning are derived. The author takes as a basis the principles proposed by Niss [26] to teach mathematics and admits that they are a model with their own spatial and temporal location, proposing time and space as practices and didactics at the same time. Graves and Suurtamm [27] discuss the connection between practices aimed at solving problems with didactics based on conversation, reasoning, and argumentation.

They base their thesis on the fact that in the teaching-learning process of mathematics, it is necessary to discuss new paradigms, including principles such as complexity and complex thought [28], and assuming that the model is complex and iterative, as mathematical learning arises through dynamic iterations in the classroom. For Goold [29], there are currently many points of view and analyses of the practices and didactics used in the teaching of mathematics to the new generation, among which she recommends setting aside memorization and moving towards conceptual understanding and the development of logical reasoning.

In the first half of the twentieth century, the practices and didactics emphasized the development of workshop skills, which led to the creation of functionalist models, that is, education that could be used. Then, the idea emerged to identify the *competencies* that students should develop to meet the demands of the workshops. However, with the arrival of new generations of students, this restrictive vision has become not only obsolete but also dangerous because the professional who only acquires skills for the workshop is a *mathematical illiterate* who does not develop skills to enter the global knowledge market.

Ackerberg [30] describes a tradition in which teachers use practices and didactics related to knowledge processes (acquire, iterate, and reinforce) and evaluation (exams and exercises). In addition, they apply various forms of work with students (group, individual, verbal, written, and using technology), which they select according to the mathematical content to be taught. This author concludes that this tradition is not the best model to achieve learning.

In contrast, Oakley [31] proposes a model to teach and learn mathematics called *diffuse mode*. For her, the practices and didactics in the classroom of this century are not enough for students to learn mathematics because students must learn to study and learn to learn (Table 2).

Table 2. Ten commandments of practices and didactics

Recommended		Not recommended	
Teaching	**Practice**	**Teaching**	**Practice**
Use memorization	Divert view Remember main ideas Highlight little	Passive rereading	Reread without motivation
Permanent tests	Records Mental Maps	Highlight too much	Highlight all Highlight to memorize
Fragment the problems	Subdivide Repeat what has been solved	Exceed trust	Make simple glimpses Look at the solutions Self-sufficiency
Learn little by little	Space the repetition	Study at the last moment	Postpone studying
Alternate techniques	Select different techniques Mix different problems Check errors	Repeat problems	Solve the same types of problems
Take breaks	Study a little every day Rest between techniques	Divert the objectives	Wasting time. Performing activities not related to the study
Apply analogies and simple questions	Explain it to other people Compare with other contexts Pronounce or write the solutions	Start without understanding	Try to solve the problem without understanding the context
Concentration	Isolate distractors Create study environment Schedule rewards	Self-interpreting	Resolve without clarifying Try to understand without discussing it with others
Sort	Sort by difficulty Select schedules	Use inappropriate study scenarios	Allow distractions Disrupt study time
Mental contrasts	Compare progress Mind maps	Sleep a little	Rest the brain very little Fatigue the brain

For Ferreira [32], mathematics education plays different roles in the training of students of this century: 1) as a school of thought because students learn to think and communicate their ideas objectively, rigorously, and concisely; 2) as a natural language because currently, dialogue occurs logically and mathematically, and 3) as a calculation tool because it contains analytical and numerical techniques to solve problems.

What happens is that with current practices and didactics, students cannot identify any of these roles because they are static, outdated, do not take into account current students' needs, and are defended and maintained by teachers as a dogma written in stone.

3.3 Teaching-learning models

A model is a system that contains principles and methods necessary to achieve specific learning and that, to be effective, must be defined by the theme, characteristics of the actors, practices, didactics, and type of training that is sought. In addition, a model's application involves neurocognitive theories and contextual realities of the classroom [33]. For Maker [34], it is a structural framework that serves as a guide to developing activities in a specific educational environment, and it is important to keep this in mind when designing curricula and defining content.

Models were introduced into education with the beginning of writing when humanity became aware of the importance of transmitting knowledge from generation to generation. Later, in the Socratic method, Plato described how to stimulate critical thinking and illuminate ideas; in Rome, Quintilian sought ways to motivate students to learn to use intelligence; Comenius was interested in having all children learn everyday things; Rousseau proposed a methodology to teach science, astronomy, and mathematics; and Pestalozzi developed a way to help children who are refugees from war to learn. In the Prussian system, education was assumed to be compulsory, and one of its central ideas was managing the skills of teachers and students in the classroom and incorporating them into the teaching process [35].

In the twentieth century, the model incorporated technological developments including radio, television, computers, the internet, and multimedia as means of support in the teaching processes. This revolution gave rise to new teaching-learning models that made learning meaningful for new generations, such as problem-based learning PBL [36], project-based learning pBL [37], learning by doing [38], and learning mediated by research [39].

In general terms, the teaching-learning models are classified as teacher-centered, student-centered, content-centered, and participatory-interactive, but generally, it is agreed that they should contain the following:

1. An identified purpose or concentration area.
2. Fundamental premises, explicit and implicit, about the characteristics of the process related to actors and teaching-learning.
3. Guidelines for developing specific learning experiences.
4. Defined patterns and requirements to achieve the objective of the learning activities.
5. A body of knowledge and research that surrounds its development and projection.
6. Demonstrable results from an evaluation of its effectiveness.

Because the choice of one model or another depends on variables such as budget, skills and teacher experience, expectations of students, and educational model, most models are limited or incorrect in at least one of these key aspects. Therefore, in many cases, when the significance of the adopted model is not properly specified, the students do not achieve true training and, on the contrary, the training process demonstrates the inefficiency of the model. This research assumes the taxonomy formulated by Nérici [40] and Titone [41] (Table 3) because the models in it have been used and evaluated over time, which allows access to literature in which their characteristics, effectiveness, and relevance to the needs of several generations of students are investigated. Although more recent proposals were found [1, 42, 43], researchers consider that their permanence over time still does not allow analysis for investigation.

Table 3. Taxonomy of teaching-learning models

Model	Family	Learning
Deductive	Representation of reasoning	From the general to the particular through deductions
Inductive		From the particular to the general through inductions
Analogical or comparative		From the particular to the particular through comparisons
Based on the logic of tradition or scientific discipline	Organization of the material	From complicated to complex according to a way of reasoning
Based on the student's psychology		From the known to the unknown through motivation
Symbolic or verbal	Relationship with reality	Only through narrations
Intuitive		Through experimentation
Passive	External activities of the student	Focused on the teacher through exposition-questions-dictations
Active		Focused on the student and supported by motivation
Globalized	Systematization of knowledge	By grouping areas
Specialized		Through individual areas
Dogmatic	Acceptance of what has been taught	By imposing the truth on the teacher
Heuristic		Through discovery by the student

3.4 Models, practices, and didactics for math training

Table 4 presents the summary of the practices and didactics analyzed and discussed by the authors, the models in which they are applied, and the observations about the results of the training in mathematics.

Table 4. Models, practices, and didactics

Practices and didactics	Model	Observations
Teacher-student integration and collaboration	Active, Globalized	Application results demonstrate better learning outcomes.
Experimentation and demonstration	Intuitive, Passive, Specialized	Mathematics must be taught by professionals with experience in the industry, not theoretical mathematicians.
Technological and conceptual tools	Deductive, Specialized, Based on the logic of the tradition	The obsolescence of these tools does not motivate the new generations.
Time and space	Passive, Dogmatic	Separation is made of the contexts, internal and external to the school, in which the student lives.
Problem-solving, Conversation, Reasoning, Argumentation	Heuristic, Symbolic	It is a complex, interactive, and dynamic process that requires the active participation of all actors.
Memorization	Symbolic, Passive, Dogmatic	The new generations perceive the world multidimensionally, so it is necessary to contextualize mathematics.
Functional, By competences	Passive, Specialized, Dogmatic	They are restrictive, and students lose the current global context.
Knowledge processes, Evaluative	Inductive, Passive	Acquiring, iterating, reinforcing, and then presenting exams is not the way to learn math.
Diffuse mode, student-centered	Active, Globalized, Heuristic, Based on student psychology	The abilities and expectations of students must be recognized.
Non-functional, Interpretative, Memoristics	Analog, Passive, Dogmatic	The new generations are irreverent, active, restless, and do not accept impositions that make no sense.

3.5 Effectiveness of models for mathematics training in the 21st century

The current education system establishes evaluation as the almost single way to know whether a student modifies his or her initial skills, abilities, and capacities after attending a specific course. However, the results of these evaluations cannot be assumed as an indication of the learning obtained because most of the teaching models of the teachers do not take into account the student learning models; therefore, it seems that each model seeks different objectives. In addition, when the student does not feel attracted, motivated, or challenged by the course, he/she simply seeks to obtain the approval of the teacher, that is, the grade and not the learning.

This context is repeated in almost all mathematics courses because the teaching models assume that, by attending and obtaining a passing grade, the student improved his or her abilities, skills, and capacities for the entrance assessment. This process of short-term memorization impairs the student's learning, in the sense that he or she does not develop the mathematical reasoning necessary for professional practice. In addition, it will not be known whether the student can effectively apply the training or experience that the course just passed should provide in a real environment. In this sense, most of the authors consulted recommend that the effectiveness of the models should be evaluated by focusing on the student's ability to analyze, understand, and solve problems and daily tasks.

Measuring changes in students' knowledge is not a static or fixed issue for all generations, but it must be dynamic and address the social demands and expectations of students. That is why it is important to know the effectiveness of teaching-learning models, particularly with the new generations because the influence of technological development distinguishes them from the previous generations. In this study, the Kirkpatrick evaluation model is adapted [44] to assess the results presented by the authors after evaluating teaching-learning models. As shown in Figure 1, the model proposes four levels.

Figure 1. Levels of the Kirkpatrick model

- Level 1. *Reaction*: student's feelings as to whether they perceive the course as favorable, attractive, and relevant to their training process. This is shown through commitment, active participation, and contributions to the improvement of the experience and in turn, offers the possibility of using and applying what has been learned in real life.

- Level 2. *Learning*: the relationship between the changes in the student's initial abilities, skills, and capacities vs the situation at the end of the course. It is the degree to which the student acquires knowledge, attitudes, trust, and commitments based on their participation in the course.

- Level 3. *Behavior*: the degree to which the student can relate what they have learned to other areas and their career, which is evident in the motivation to continue and in the development of skills to self-train and seek new challenges and knowledge.

- Level 4. *Results*: the degree to which the student has developed critical thinking and logical reasoning, in addition to mathematical knowledge. The results have short-term effects on the development or strengthening of their logical-interpretative and abstractive capacity to understand and solve real problems.

According to this model, no one level of evaluation is more important than the others because the true utility of the evaluation is achieved by analyzing the results in each one. In addition, the result in each level provides diagnostic control points for problems that may result in the evaluation of the next level. For example, if the student does not learn in the course (Level 2), the feelings expressed in Level 1 will denote the reasons why they are not learning. In contrast, if the student does not apply what they have learned (Level 3), it may be because they did not learn what they needed to (Level 2). The methodology applied to evaluate the effectiveness of teaching-learning models for mathematics training in the 21st century is assumed here as an incremental process, where the student should improve their training at one level based on the results obtained in the previous level.

After analyzing the results of the case studies and making the triangulation with the didactics and practices with which teachers apply the models in the classroom, Table 5 presents the results of the evaluation of the effectiveness of the models for training in mathematics. Only the case studies and the results published in this area are summarized (Table 1), although the authors can study different courses at the same time. The effectiveness of the models is calculated based on the qualitative and quantitative results published in the case studies, about the learning achieved by the students at the end of the course. Subsequently, the models are analyzed and weighted according to the levels of the Kirkpatrick evaluation model: *Excellent* E for level 4, *Good* G for level 3, *Regular* R for level 2, and *Deficient* D for level 1. Models for which no case studies were found were assigned a *Not Applicable* NA assessment. In the column of observations, the analysis is summarized for the results that the authors obtain according to their research.

Table 5. Efficacy of teaching-learning models for mathematics training in the 21st century

Model	Effectiveness	Observations
Deductive	D	The model is deficient for learning because students do not have a solid foundation of mathematical principles
Inductive	R	Individual and isolated explanations do not allow the student to interconnect what he or she learns with knowledge in other areas
Analogical	NA	No case studies were found
Based on the logic of the tradition	D	By structuring the course sequentially, without allowing the student to alter the order to seek connections of what he or she learns, he or she loses interest and will only seek to obtain a passing grade
Based on the student's psychology	G	If the student can experience mathematics based on his or her expectations and knowledge, he or she finds challenges that lead him or her to seek more training
Symbolic or verbal	NA	No case studies were found
Intuitive	G	Students become involved in their learning and seek to validate their experience through the concepts learned in the classroom
Passive	D	If the teacher is the center of the teaching-learning process, the student becomes an object in the context of the classroom and loses all interest in learning
Active	G	The student participates, discusses, and proposes, so he or she is interested in learning so as not to lose the rhythm of his classmates
Globalized	E	Having several professors from other areas or courses analyze the solution to a problem challenges students to increase their knowledge in mathematics to join the discussions and collaborate on solutions and proposals
Specialized	R	The student does not find meaning in independent mathematical learning because he or she cannot connect it to other areas
Dogmatic	NA	No case studies were found
Heuristic	E	When the principles of mathematics are involved in specific challenges, which the student must overcome, integration is achieved between teamwork and competition for learning

4. DISCUSSION

This study was carried out to determine the effectiveness of the teaching-learning models for training in mathematics, from the analysis of the results of the case studies that were found in the literature. In the triangulation to achieve this objective, *didactics, practices,* and *teaching models* used by teachers in the classroom, *learning* models that structure students inside and outside the classroom, and the *Kirkpatrick evaluation model* were studied.

Regarding practices and didactics, it was found that teachers prefer to use those that require less preparation, while they generally apply only exams (exercises), instead of problems, practice, or projects, to evaluate the knowledge that students acquire. This allowed us to identify two attitudes towards mathematics in the classroom: 1) the learning model of the students, in which they expect didactics that allow them to improve their level of learning; and 2) the teaching model of the teachers, which the students do not value because it inspires fear and discomfort and does not respond to their expectations. In this context, some authors emphasize the importance of the learning environment for a mathematics course, something that teachers overlook because they consider themselves the center of the system and because they imagine that their didactics and materials are sufficient for learning.

These realities are obstacles to the success of mathematics teaching because the new generations expect didactics and practices that motivate and challenge them to stay in the course. For them, memorizing concepts is a forgotten practice because they have technology at their service and expect to be guided to build and discover knowledge through questioning and discussions, which they can then take advantage of to develop logical-mathematical reasoning and structure permanent learning.

This has caused students to lose interest in mathematics because they do not find that it has meaning or importance. In light of this, teachers are expected to innovate their teaching models, didactics, and practices because they are no longer attractive to new generations. If the final objective of the training in mathematics is to develop or strengthen the logical-interpretative and abstractive capacity of the students in such a way that they structure mathematical reasoning for the enrichment of their training, then the teachers should strive to improve their training, gain experience in the industry and bring it to the classroom, and understand the student learning model.

Another issue that is overlooked is that students' nature, experience, expectations, and training needs in mathematics are very different today because current generations are atemporal and multi-dimensional. Therefore, restricting mathematical training only to theoretical issues is a weakness that can lead to desertion and underappreciation of the area. This should motivate teachers and institutions to innovate the curricula, contents, practices, and didactics used because the teaching-learning model must add experience, practice, and challenges that keep the students captivated and motivated to learn more.

However, as evidenced in the chapter analyzed, teachers seem oriented only toward *dictating* content, meeting time requirements, performing exams, and writing notes. All this is out of place for the current generations because they consider that they must sacrifice their time to attend the mathematics course, and if they do not, they delay their educational process. The reality is that students have access to all types of technologies that are not used effectively as part of the teaching model.

Most of the studies analyzed conclude directly or indirectly that the deficiencies in mathematical knowledge and the lack of didactic updating of the teachers are elements that directly affect the level of student learning. In this sense, teachers should form a learning community and coherently and systematically build a base of knowledge, good practices, and success stories that will help them stay up-to-date and understand the new generations of students. If the request is to implement practices and didactics that draw attention and challenge students, then they must start by living them personally before taking them to the classroom.

Additionally, the obligation in the teaching-learning models of this century is to modify the evaluation because today students are required to solve problems and execute projects, something that teachers do not apply in their courses. Among the various works that recommend and describe innovative practices, it is worth mentioning the Education Alliance and Andrew University for their contributions to the innovation of teaching mathematics.

Table 5 shows only two teaching-learning models that are located in Level 4 of the Kirkpatrick model (globalized and heuristic) and three in Level 3 (based on the student's psychology, intuitive and active). According to the researchers, these models allowed students to develop critical thinking and logical reasoning on a differential scale relative to the other models. Therefore, it is worth wondering: what would happen if teachers applied a combination of these models to teach math? For example, when composing practices and didactics based on the models of the psychology of the student and the globalized, or the active and the heuristic, teachers could eliminate the disadvantages of each one and obtain better results by developing or fully strengthening the logical-interpretative and abstractive capacity of the students.

Research limitations

- Most of the studies analyzed in this study show results in terms of practices, didactics, and content but do not take into account the student variable, so additional research is needed in which this variable is included, involving the aspects that affect students' predisposition towards mathematics, such as prior knowledge, cultural stratum, major and age.
- Although it is mentioned among the variables analyzed, the influence of the institutional political variables and institutional educational project on the results is not clear. Because these variables could also impact the effectiveness of the models, they should also be included.
- Another variable that should be included in a subsequent investigation of this subject is the training of teachers, that is, whether they are instructors, graduates, engineers, or professionals in other areas.

5. CONCLUSIONS

To gain a broad understanding and present results based on facts, any study aimed at determining the effectiveness of a teaching-learning model must take into account the variable nature of teaching practice in the classroom, the influence of schools of thought and training, the multidimensionality of the processes in the classroom, the interests and expectations of the students and the social demands because these aspects create an environment in which training in any area becomes a challenge for this century. In addition, we must recognize the new generations' unique characteristics and the technological developments and their participation as variables of analysis in the teaching-learning process.

In this study, it was possible to determine the effect that these and other variables have on the effectiveness and results of training in mathematics courses and consequently on the level of student learning. This highlights the responsibility of each of the actors involved in the process, from the teachers, students, and curricula to the contents, practices, and didactics used. This chapter analyzes the relationship between the application of teaching-learning models and the level of training in mathematics, to determine its effectiveness, by analyzing the initial and final situations, for the development of skills, abilities, and capacities that students exhibit at the end of the course.

Because every training process is complex, these principles and variables should be considered as a whole and not in isolation, for their interrelations impact the learning that students achieve. That is why the weaknesses of the study are presented as a basis for future work in which they are integrated into the analysis of efficiency. This alignment becomes an important innovation to demonstrate the need to modify how new generations are trained in mathematics. It is recommended that any initiative for change is negotiated among all actors and that adequate financial and human resources be assigned so that it does not become one of the many attempts that have failed.

The results presented in this chapter emerged from the review of the literature on case studies, in which the changes in student performance are evaluated after completing a mathematics course whose teacher used certain practices and structured didactics in a teaching-learning model. The result cannot be considered definitive because those works do not involve all the variables involved in a training process; therefore, further research is proposed that includes an evaluation of the development of the logical-interpretative and abstractive capacity of students who complete a mathematics course.

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XV

Why do students drop out of engineering careers? Analysis of incident factors

The fact that a student abandons his or her formative process at any stage has always been considered a serious problem because it affects both the educational system and the social and cultural system. This article presents the results of an investigation to determine the factors that have the greatest impact on the decision to drop out of an engineering program. A research process was structured between 2021 and 2023 in which three main tools were designed and applied: 1) online consultations, 2) email surveys, and 3) personal interviews. It was found that the factors with the highest incidence in the decision to leave the program are the lack of engineering skills, incipient development of logical thinking, and deficient mathematical skills, in addition to others related to professors, institutions, and companies. These factors have the characteristic that the actors themselves can intervene in them, so the education system should pay more attention to them.

1. INTRODUCTION

The fact that a student drops out of the educational process at any stage has always been considered a serious problem because it affects both the educational system and the social and cultural system. This is because, by abandoning the process, people do not fully develop the necessary abilities, skills, and abilities, so they present serious educational deficiencies that affect their quality of life. For this reason, they do not find jobs with adequate salaries, they do not meet their health, housing, and recreational needs, and most of them lag in terms of professional and cultural development in this society. Although this problem affects all areas of education, and although there have been numerous investigations to determine the reasons for dropout in a general context, few have focused on analyzing this situation specifically in engineering programs.

The issue is that dropout in these programs has an impact beyond the personal, family, and social life of the students, so it has attracted the attention of state organizations, universities, and companies that try to solve it by various means and with multiple alternatives. However, the panorama in the area does not seem to improve because the dropout rates are maintained or increased in this century. On the other hand, the reality is that in the globalized world, the demands in terms of abilities, skills, and abilities to get a job have expanded and diversified because candidates with higher levels of knowledge are required and the fact of not having them is not forgiven.

Without poring over the innumerable reasons why this problem should be addressed in education in general, the situation becomes more critical about engineering, because the 21st century revolves around its developments and discoveries. Then, a kind of closed cycle is generated for a reality in which good engineers are needed, but students do not want to take these programs [1] and, those who decide to do so, abandon them in a very short time. For this and many other reasons, the issue of engineering student dropouts should become a priority for the state, academia, society, and industry, while requiring more attention from researchers, legislators, and educators at all levels. It is necessary to find a solution to regulate and reduce the dropout rate in engineering programs, because otherwise, at a later time, it will be difficult to have the necessary human resources to meet the demands and needs of a society that is used to enjoying and coexist with the technological developments created by these professionals.

This situation generates worldwide concern due to the possibility that, in the next decade, engineering programs will not have the number of students required to meet the aforementioned social demands [2]. Moreover, the most influential works in the literature on this issue are restricted to the most developed countries, where the problem is greater [3-7]. On the other hand, there are widely published works that analyze personal and social variables, institutional practices, state policies, and social influence, which interact and have an impact on the permanence or not of students in the university; but they do not analyze or present alternatives to the problem of the factors that the direct actors can manipulate and adapt to remain in an engineering program.

In this sense, the objective of the present research is to analyze these factors, while presenting alternatives for joint work among the actors to find options that motivate the next generation, first, to select engineering careers and, second, to remain in them until obtaining the respective degree. On the other hand, although this study is focused on analyzing a population made up of people who dropped out of engineering studies in the first year (2021), second year (2022), or third year (2023), the alternatives are projected prospectively to be applied to the first wave of students of the new generation, who will enter higher education in the next decade, that is, those who are currently in high school.

Although the researchers participating in this study do not have a marked predilection for the various classifications and characterizations that many authors publish about generations, it could be said that the primary population of this study belongs to the last wave of the millennial generation, i.e., those born between 1998 and 2003 and that, at the same time, it is considered as a transition generation towards the so-called digital generation, because they are not exclusively located in any of them. On the other hand, alternatives to improve the problem situation are proposed for students who make up the first wave of the so-called digital generation, i.e., those born between 2004 and 2010.

The rest of the document is structured as follows: the second part describes the state of the art, with arguments about why to be an engineer and a description of the works related to the study of engineering student dropout; the third part describes the method applied in the research and its limitations; then, the fourth part presents and discusses the results of the central research and the parallel consultation; the fifth part contains an analysis of the results obtained in both studies and then the respective conclusions and references are presented.

2. STATE OF THE ART

2.1 Why become an engineer

Analyzing this issue is not easy because there are many diverse reasons why society and students support the need or decision to become engineers [8-10]. In each study, reasons are found that, in most cases, are complementary or simply the opinions of individuals and students who are not interested in answering surveys or queries of this type. When comparing these results, the predominant reasons for studying engineering tend towards factors such as building machines, conquering space, developing video games, and being a quick millionaire, among others. It seems that students do not have a clear idea of why to study engineering, which is reflected in their appreciation of what an engineer should do [11].

In this regard, many institutions, concerned about the lack of students in engineering faculties [12], carry out motivational campaigns with the idea of convincing high school students to choose engineering careers, but their motives are nothing more than figures and statistics that do not demonstrate the importance of these professionals for society. The point is that engineering does not seem to be for everyone and whoever decides or tries to study it must have a special predisposition, which not all students possess [13]. Beyond the ideas that are popularly wielded, some of the reasons why one should study engineering are:

1. *You develop a different way of thinking*. Because you learn to think like an engineer, that is, logically through critical analysis, which leads to better, more objective, and less emotional decisions. These skills, abilities, and capacities are necessary to shape the current and future development of a society influenced by technological developments.

2. *One learns to be creative*. This society has a strong dependence on engineering products, which offers a wide field for engineers to be creative and engineer necessary and useful developments to put them at the service of mankind. Only with creativity can the future be envisioned, and engineers develop special capabilities in this regard, as they are continually challenged by societal demands.

3. The engineer is a *curious professional* who is challenged by the complications of today's problems and to find the best possible solution to them.

4. Engineers are *unique professionals*, with significant differences from the rest, because they develop an appetite for searching for answers and, for the most part, they are good at devising, developing, and building things.

5. To be an engineer *it is not necessary to be good at mathematics*, from the point of view of memorizing formulas and equations, but to develop the ability to understand and comprehend them differently from others.

6. The engineer *visually materializes the physical* before discovering the mathematics and logic of its design and, if the object is built, disassembles it in his mind to learn its principles of operation.

7. To be an engineer it is not enough to have accumulated experience or visual-spatial thinking, you must also be aware that at any time *you can make a mistake*, therefore, you must reflect, doubt, and inquire about everything that you cannot visualize or do not know completely.

In short, to be an engineer it is not enough to develop artistic abilities and skills or to master the resources and forces of nature in the design of solutions to the problems of humanity; nor is it enough to master mathematics and scientific principles because, although they are necessary, the exercise of the profession must be accompanied by a large dose of inventiveness, innovation, creativity, human quality, management, teamwork, assertive communication, consolidation, design, structure, aesthetics, and ethics. Otherwise, it becomes a catalog of data, limited to use techniques, standardized methods of procedures, calculations, and engineering specifications, without exercising their creativity and inventiveness. All this is part of the motivations for studying or abandoning engineering studies and should be taken into account when structuring, implementing, and offering programs in this discipline.

2.2 Related work

Table 1 presents a summary of the most widely accepted studies in the literature that present objectives related to the present study.

Table 1. Related works

Reference	Summary
[14]	It presents an analysis of the situation of university dropouts in general in Spain; a theoretical profile is elaborated with the definition, causes, explanatory models, and solutions to the problem. It is a study of general coverage and not exclusively of engineering.
[15]	Based on data collected at five institutions in the U.S. from 2003 to 2004, the authors analyze the causes of dropout in engineering; a measure of the factors that lead students to drop out is presented, but they are broad and not specific and control for individual students, faculty, or institutions.
[16]	The authors review research on school dropout to understand why it occurs; they analyze the causal relationships between the factors reported and the individual decision to drop out of school. Two types of factors were found to be associated: 1) with the individual characteristics of the students, and 2) with the characteristics of their families, schools, and communities. The study is general and does not individualize the causes for dropping out of engineering.
[17]	This review looks at the characteristics of engineering students and how they affect their educational outcomes and proposes a classification taking into account external, cognitive, affective, and demographic aspects to find the causes of dropout. The authors do not analyze the characteristics that the actors can control but rely on those that others have proposed.
[18]	The purpose is to find the factors that influence the decision to drop out of engineering studies from the analysis of variables that predict desertion and take into account academic and non-academic aspects. The study is general and covers factors that cannot be controlled by the students.
[19]	This study analyzes the dropout or career change of students in STEM areas between 2003 and 2004. The results show several factors that motivate attrition from these programs, mainly related to a lack of adequate training in mathematics, but the more direct and individual control issues, such as motivation and predisposition to enter, are not analyzed.

[20]	It presents research on school dropout and analyzes the causes reported by students in other studies. The authors take into account diverse factors, from personal, family, social, and cultural factors, to those of other actors. The coverage is broad and attempts to combine so many variables that it cannot be considered a study of particular self-controlling causes.
[21]	A review of the literature on the reasons for attrition in engineering programs is presented. Six general factors are identified to which alternatives conducive to student retention are presented. It is a generic analysis and does not discriminate between factors controllable and not controllable by actors such as students, professors, and institutions.
[22]	This article presents the results of an investigation into the experience of four students who dropped out of engineering studies. Although the authors involve individual factors, they consider them from the point of view of the students and not of the other actors. In addition, they analyze only four students, a population that does not seem representative.
[23]	The author presents a study to determine the factors that led ten students to drop out of engineering studies. As often happens in this type of research, the results of a small sample cannot be considered representative. In addition, only factors from the student's point of view are covered, without involving professors and institutions, which also influence dropout.
[24]	The study presents a thematic analysis of the factors that lead engineering students to enter and drop out of these programs, based on data collected from work with students. In general, it only analyzes the data from the point of view of one actor, leaving aside that of others who influence or determine the decision to drop out.

3. METHOD

In the past, several works have been presented analyzing correlations between the different factors that lead a student to drop out of an engineering program [5, 25-29], in which a series of characteristics that strongly influence this decision were identified, but which, according to [17], have not yet been structured in a way to categorize them. For this reason, and after conducting a structured analysis of the related works most widely accepted in the literature, the team concludes that, in general, these factors can be classified as 1) *Self-managed* by the student, 2) *Externally managed,* and 3) *Unmanageable*. Based on this analysis, the authors decided to investigate the incidence of the first ones in the decision to abandon an engineering program, taking into account that these factors are manageable by the student, either to acquire them, develop them, or improve them; in addition, and carrying out a prospective analysis because alternative solutions can be sought so that students of the new generation do not withdraw from these careers in the future.

Therefore, the purpose of this research is: 1) to determine the incidence of the factors that students can control in their decision to abandon an engineering program, 2) to know the criteria that students of the new generation externalize as arguments that influence them to study engineering, and 3) to present an analysis of different solution options, to accompany the students of the new generation in their career selection process, specifically engineering, and to advise them in the process so that they do not abandon it. On the other hand, the questions this work seeks to answer are 1) What are the factors that prevail when deciding to abandon an engineering program? And 2) How do address and prioritize these factors so that the students of the new generation choose to study this discipline and remain in the process until they reach their respective degrees?

A three-year research process was structured, in which three main tools were designed and applied: 1) online consultation, 2) email surveys, and 3) personal interviews. The research was conducted with engineering dropouts in Australia, Germany, the United States, Argentina, and Colombia, and was developed in three phases: 1) 2021, people who entered this year at the university and dropped out in the same year, 2) 2022, those who entered in 2021 and dropped out in the second year, and 3) 2023, those who entered in 2021 and dropped out in the third year. The working team is made up of research assistants in each country distributed as follows: 5 in Australia, 6 in Germany, 8 in the United States, 5 in Argentina, and 3 in Colombia, in addition to the principal investigator and a Master's student developing his research thesis in the project. The research methodology sheet is presented in Table 2 and examples of the structured questions in the tools are shown in Table 3.

Table 2. Methodological sheet of the central investigation

General					
Applied tools	Online consultation E-mail survey Personal interview				
Actors	Direct: Individuals who dropped out of engineering careers in the first three years. Relational: Universities, professors, companies.				
Factors analyzed					
Of the person who drops out of school	Learning method, predisposition, background, cultural stratum, cognitive capacity, engineering skills, logical thinking, and mathematical skills.				
From the teacher	Teaching method, professional experience, knowledge updating, research experience, human being, professional being, global being.				
From the university	Curricula, curricular integration, admission system, infrastructure, retention strategies, internationalization.				
From the company	Hiring policies, real need, incentives.				
Population					
	Australia	**Germany**	**United States**	**Argentina**	**Colombia**
People who left	84	78	134	151	137
Universities	5	7	10	6	8
Companies	9	10	19	11	13

Table 3. Typical questions in the core research tools

Type of question	**Valuation**				
On a scale of 1 to 5, where 1 is no incidence and 5 is incidence: What was the incidence of these factors in your decision to abandon your engineering career?					
	1	**2**	**3**	**4**	**5**
My learning method					
The teacher's teaching method					
The curriculum and curricular content of the program					
The valuation that the company gives to engineering degrees					

In addition to the central research process, the work team conducted a parallel consultation with high school students, aimed at finding out their preference for studying engineering, while at the same time analyzing the level of development of the factors that, according to the central research, influence the subsequent decision to abandon a program in this area. The idea is to find out if they plan to study engineering and, for those who answer yes, to ask them about the level of development in which they have the characteristics that a student needs before and during an engineering career. A sample of high school students was taken, in the same countries as the central research, who were followed up at three points in time: 1) in the antepenultimate year of this phase of training (2021); in the penultimate year (2022); and 3) in the last year (2023). The same consultation was applied in the three years and to the same population, with the idea of finding variations, changes in the assessment, and new or discarded factors; in addition, to find out if they continue interested in studying engineering or if they change their mind. The tool applied was the personal interview, whose methodological form is described in Table 4, and Table 5 shows the type of questions applied in the interview.

Table 4. Methodological sheet of the parallel consultation with high school students

General	
Applied tool	Personal interview
Actors	High school students
Factors analyzed	
From the student	Learning method, cultural stratum, access to and use of technology, course concept, problem-solving, entertainment media, media consumption, peer or individual entertainment, and virtual or real games.

Population					
	Australia	**Germany**	**United States**	**Argentina**	**Colombia**
Antepenultimate year	35	42	68	89	72
Penultimate year	30	40	60	86	65
Last year	28	35	45	81	54

Table 5. Sample questions in the parallel consultation with high school students

Type of question	**Valuation**		
	Yes	**No**	**Sometimes**
I plan to study engineering when I finish high school			
I have an organized way of studying			
The course in which I work best in mathematics			
I have no problem studying and having fun with my classmates			
My work is carried out in a clear and organized manner			

4. RESULTS

4.1 Central Research

As mentioned before, for the work team, the factors that influence the abandonment of a career can be classified as 1) Self-managed, 2) Externally managed, or 3) Unmanageable by the students. They directly or indirectly manipulate the first ones, because they can modify them through structured behaviors or procedures, to improve that weakness or shortcoming in their formative process. For example, only the student can manipulate his or her predisposition towards a career, either by seeking counseling or by self-training to overcome that *weakness*. The same can be said of the incidence factors related to professors, universities, and companies, because, individually, they can manipulate them to help solve the problem of students dropping out of the engineering program.

By the above, in the central research process, a population of 584 people who dropped out of an engineering program in the first three years of their studies was selected; 36 universities collaborated with contact information and 62 companies provided data on their engineering hiring policies. Table 6 details the average rating that the population consulted gave to the incidence of the factors at the time of deciding to leave an engineering program. Those consulted were not individualized by program, but were analyzed in all areas considered as engineering per se; furthermore, it was not taken into account whether the decision to drop out was to change careers or to completely give up their training process.

Table 6. Average evaluation of the incidence of factors

Actor	**Factor**	**Description**	**Average valuation**
Student	Engineering skills	Innovation, adaptation, spatial, teamwork	5
	Logical thinking	Analysis, argumentation, reasoning, justification	5
	Mathematical skills	Organization, relationship, location, complexity	5
	Background	Secondary school educational outcomes	4
	Cognitive capacity	Learning, reasoning, attention, memory	3
	Learning method	How you structure your study process	3
	Predisposition	Vocational aptitude for engineering	3
	Cultural stratum	Reading level, inquiry level, personal motivation, ethics, etc.	2
Professor	Teaching method	Methodologies, didactics, practices, motivation	4
	Being global	Links to the course internationally and in other languages	4
	Knowledge update	Continuous training in the topics of the subject matter	4
	Research experience	Conducts research and validates its knowledge	4
	Human being	First and foremost, he is a person with faults and virtues	3
	To be a professional	He is ethical, upright, and respects his profession	3
	Professional Experience	Knows the issues and content beyond the classroom	3

University	Curriculum	Curriculum and curricular content, evaluation system	5
	Internationalization	International relations exist and are cultivated	5
	Flexibilization	Between programs, universities, companies	4
	Curricular integration	Subjects are not islands, contents have integration	4
	Infrastructure	Sufficient to meet program needs	3
	Retention strategies	The student is more than a number	3
	Entry system	According to the study area	2
Company	Real need	Professionals, technicians, operators or self-learners	5
	Hiring policies	Valuation of the degree, experience, knowledge	3
	Incentives	Sense of belonging through stimuli	3

This assessment shows that the factors with the greatest impact on dropout are characteristics that people analyze in their process and that, with proper planning, contingency plans could be established so that the new generation can easily overcome them. For example, if the generation in which the population of this study is enrolled recognizes that it has deficiencies in the development of engineering skills, logical thinking, and mathematical skills, it is advisable that, for the new generation, programs, and strategies be designed to overcome them before selecting a program at the university.

Likewise, the other actors could also structure plans that respond to this assessment, for example, universities should analyze their curricula and the curricular integration established for the engineering programs they offer. This could mitigate the problem of desertion that will arise when students finish high school and enter higher education, which will happen in the next decade. In the case of companies, greater attention and planning should be paid to their job offers, because this population considers that the fact that they are not clear about the characteristics and functions of the engineer they require has a high impact on their decision to abandon their careers.

Regarding the analysis by country, Figure 1 shows the percentage incidence of the factors that each actor can manipulate in the decision to leave an engineering program. It can be seen that people from Latin America value less the incidence of the factors they can manipulate, giving greater weight to the factors they cannot manipulate, i.e., those of professors, universities, and companies. On the other hand, people in other countries place greater value on their factors, particularly in Germany, and much less on those of universities, professors, and companies. This may be because they have a higher cultural stratum than Argentina and Colombia. After all, they have been trained in educational systems in which self-criticism and personal analysis are very important. Also, teachers consider themselves professionals and society recognizes them as such.

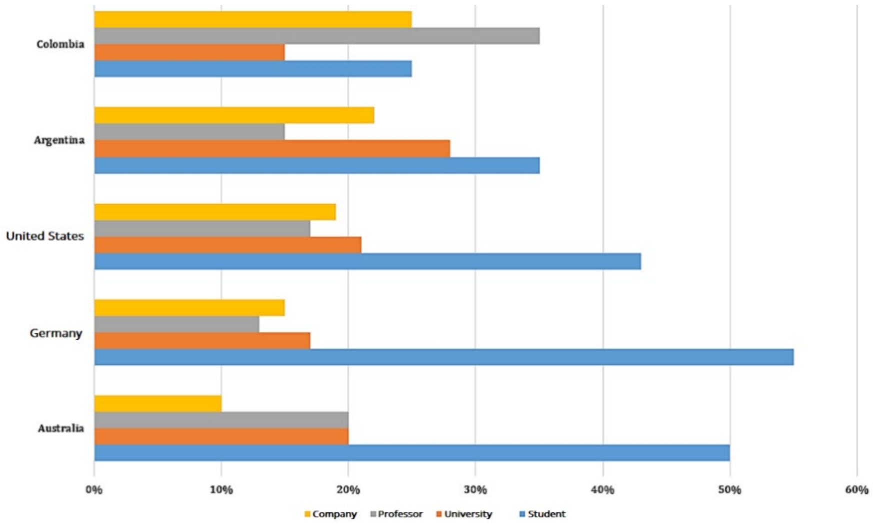

Figure 1. Percentage incidence of factors by stakeholder and country

In any case, the study population attributes greater incidence to factors that they can manipulate, i.e., in the decision to leave an engineering program, issues such as background (learning results in high school), engineering skills (innovation, adaptation, spatial, teamwork skills), logical thinking (analysis, argumentation, reasoning, justification skills) and mathematical skills (organization, relationship, location, complexity skills), which every engineering student should develop, take precedence in the decision to leave an engineering program.

On the other hand, in the first year of study, the highest dropout rate among engineering students is observed in Table 7. It is striking that in the third year in Latin American countries, there are fewer dropouts than in the other countries, but at the same time, in the first year, they occupy the first positions.

Table 7. Total career dropouts by year and by country

Country	First-year	Second-year	Third-year
Australia	32	28	24
Germany	24	32	22
United States	75	38	21
Argentina	99	36	16
Colombia	78	40	19
Total	308	174	102

Figure 2 shows the results in terms of the incidence of the factors in dropout, according to the year of the student's career. This means that, as students advance in their careers, they are more aware that their weaknesses will not allow them to adequately complete the engineering program. At the same time, the importance of company factors is increasing, because, possibly, they are beginning to analyze their future as professionals.

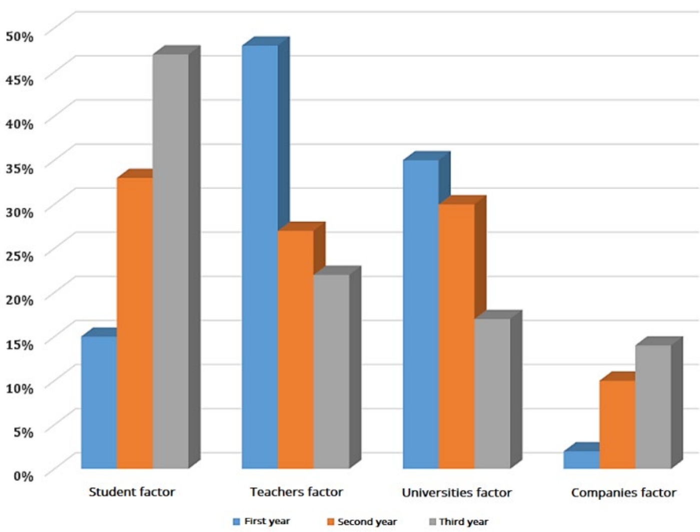

Figure 2. Incidence of dropout factors by year of study

4.2 Parallel consultation

We worked with an initial population of 306 students in their junior year of high school, but because the objective was to consult them again one and two years later, this population was reduced, for various reasons, to 281 in the junior year and 243 in the senior year. The information was collected through personal interviews and the result is shown in Table 8. The same factors evaluated in the central research were taken for the people who dropped out of engineering programs, only for the student actor, through questions whose answers could reflect their degree of development, age, and high school level.

Table 8. Results of interviews with high school students

Factor	Description	Antepenultimate year			Penultimate year			Last year		
		Yes	No	Some times	Yes	No	Some times	Yes	No	Some times
Plans to study engineering	An inclination for this discipline	65%	25%	10%	34%	58%	8%	34%	58%	8%
Learning method	Has a structured way to study	27%	41%	32%	24%	40%	36%	24%	40%	36%
Predisposition	Reflects a vocational aptitude for engineering	31%	45%	24%	22%	40%	38%	22%	40%	38%
Background	So far, he has achieved good learning results	67%	30%	3%	50%	45%	5%	50%	45%	5%
Cultural stratum	Demonstrates good levels of reading, inquiry, personal motivation, and ethics, among others	28%	51%	21%	21%	52%	27%	21%	52%	27%
Cognitive capacity	Develops learning, reasoning, attention, and observation skills to a good degree	25%	45%	30%	28%	43%	29%	28%	43%	29%
Engineering skills	Demonstrates inclinations for innovation, adaptability, spatial location, and teamwork	33%	52%	15%	40%	39%	21%	40%	39%	21%
Logical thinking	Shows adequate levels of analysis, argumentation, reasoning, and justification	22%	27%	51%	43%	21%	36%	43%	21%	36%
Mathematical skills	In the face of hypothetical problems, reveals organization, relationship, location, and attention to complexity to address them	18%	60%	22%	33%	37%	30%	37%	33%	30%

The results in key factors for the professional performance of engineers, such as logical thinking, mathematical skills, and engineering skills, reveal that the population, as a sample of the new generation, has the potential to study engineering. The problem is presented in factors such as predisposition to study this discipline, cultural stratum, and background, in which a progressive decrease is observed, something that, with an adequate training process, could be developed and used as complementary factors to the first ones.

In any case, it can be observed that this generation has the necessary characteristics to study engineering, but that, due to various circumstances, in three years they lose interest in taking these programs. This requires the intervention of the education system, in the sense of analyzing the formative progress of this generation from the time they enter, at least, high school, with the idea of strengthening these capacities and making them decide to study engineering through an adequate orientation and follow-up process.

Figure 3 shows the comparative curve between the main factors and the idea of studying engineering in the three years consulted.

One possible reason for this situation is that, as they progress in their studies, they become more involved in social situations in which they become aware of the advantages that some professions have over others at the time of practice.

For example, companies value abilities, skills, and abilities more than university degrees, i.e., know-how is more important than years of higher education. Therefore, although they have the potential to become good engineers, they decide not to study these programs because of the time required for their study; they prefer to self-train or take short courses to develop skills to *operate tools* because that will allow them to earn income quickly.

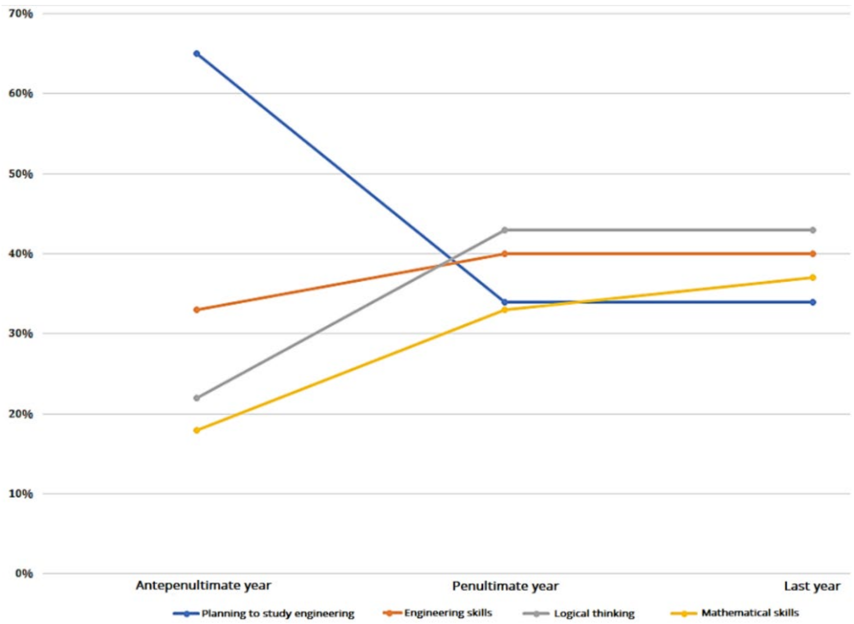

Figure 3. Comparison between the idea of studying engineering and some representative factors

Table 9 shows the results by country and representative factor in each year consulted with high school students. According to this information, students from Germany show better results than in the other countries, while Colombia has the lowest values. Once again, their interest in studying engineering declines, although they improve in terms of the predominant factors that an engineer should develop.

Table 9. Results by country and predominant factor in secondary school

Country	Planning to study engineering			Engineering skills			Logical thinking			Mathematical skills		
	2021	2022	2023	2021	2022	2023	2021	2022	2023	2021	2022	2023
Australia	63%	33%	31%	34%	41%	42%	22%	45%	46%	20%	36%	41%
Germany	61%	32%	30%	35%	43%	44%	24%	47%	46%	22%	38%	43%
United States	66%	35%	33%	31%	38%	37%	19%	38%	37%	17%	32%	32%
Argentina	67%	36%	35%	32%	40%	40%	19%	36%	38%	16%	30%	35%
Colombia	65%	35%	35%	30%	38%	37%	17%	35%	34%	13%	25%	30%

5. DISCUSSION

When making a triangulation between the information collected in the central research with the results of the interview with high school students, it can be concluded that there is a need for attention and solution plans to the problem of the low interest of students of this century to study engineering programs, although they demonstrate abilities, skills, and capacities to be good professionals in this area. This panorama could be improved if professors, universities, and companies would pay more attention to the factors involved in the decision to abandon engineering.

In the case of teachers, a development plan should be structured to improve and/or innovate, characteristics that students rate as having a high incidence in their decision to leave:

1. *Teaching method*: In terms of methodologies, didactics, practices, and motivation in the classroom.
2. *Be global*: To relate the course globally and in another language.
3. *Updating of knowledge*: Because they need to be permanently trained in the topics of the subject.

4. *Research experience*: Research the contents of their courses and validate their knowledge with the reality outside the classroom.

In addition, these factors are self-managed because they are the ones who can improve them to bring their knowledge to the classroom, through methodologies and didactics that keep students motivated and interested in staying in their careers and achieving their respective degrees. On the other hand, as far as the universities are concerned, the factors with the greatest incidence in the decision to drop out are:

1. *Curricula*: In the sense that they perceive that the curricular mesh and contents do not fit what they know and what they have access to through the network; furthermore, that the evaluation system is obsolete and is not a unit of measurement of progress in the development of the skills, capacities, and abilities they need to be engineers.

2. *Globalization*: A factor in which they state that there are no real international relations that they can benefit from to move to other countries or institutions; something they consider essential for an engineer in this century.

3. *Flexibility*: Both to achieve their professional degree and to interact with other programs, disciplines, and universities or companies, where they are offered scenarios adjusted to their family, work, or personal realities.

4. *Curricular integration*: To show them the importance and necessity of each subject in their training process as engineers, because they consider that the subjects cannot be worked as islands and disintegrated contents.

This should be used as an opportunity for universities to propose action plans to improve these characteristics. For example, annually update engineering curricula and content and, together with innovative and qualified professors, offer challenging and motivating curricula so that students perceive the challenge of staying in the program since they will be able to become global engineers.

For their part, companies also present factors that have a large impact on the decision of students to abandon their engineering studies. For them, the character with the greatest incidence is that they do not adequately analyze their needs for engineers, that is when they request or hire these professionals they do not know if what they need is an engineer, a technician, or an operator.

They hear that the professionals are disappointed because they are not able to practice engineering properly. After all, the company performs tasks that do not require a degree such as the one they have. Companies hire engineers only to show indicators before state agencies when what they need is a technician to perform repetitive functions, something that discourages students from continuing in their careers.

On the other hand, for several years now, in many countries, companies have been valuing what people know how to do, above the degree they hold. In this scenario, it is in their interest that you enter by contributing to production immediately because they consider it a waste of time and money to have to train an engineer in the functions in which he/she can develop his/her skills as a professional. Students are aware of this from the first year of their career and they support, at the most, to the third year to withdraw and seek self-training in what companies need most.

Now, the factors that students can manipulate, which they consider to have a high incidence in their decision to leave an engineering program, are:

1. *Engineering skills*: Because they consider that they have not developed innovative, adaptive, spatial, or teamwork skills, and when they are in the second or third year of their career, they realize the importance of their professional practice.

2. *Logical thinking*: from the first year they notice that they require skills for analysis, argumentation, reasoning, and justification, but they feel frustrated because, as they advance in their career, they do not develop them at the level required by the program, lose interest and decide to drop out.

3. *Mathematical skills*: A theme that has been emphasized to them since school is that it is a difficult area and that only some can succeed in their university study; therefore, when they cannot structure their work in an organized way, finding relationships and delimiting the necessary locations, and not responding to the demands of the complexity of the problems, they realize that their mathematical skills are not at the level they need to study engineering; then, their logical decision is to drop out of the program.

4. *Academic background*: The university environment shows them that the learning results in high school could be a mirage, in the sense that the level of development they achieved does not come close to what is required in a university program, even though they have obtained good grades and recognition.

As mentioned in the research method, these factors were selected because they can be manipulated by the students themselves, that is, they are responsible for improving or not the level of development and weaknesses in each of them. Most do not understand this, or simply become disillusioned by not advancing at the same pace as their peers, and choose to drop out of engineering studies. This becomes an opportunity for secondary schools to intervene in these factors so that the school takes a leading role in detecting the inclinations of its students towards one career or another.

Due to the above, the authors of this work decided to interview students in their junior, senior, and senior years of high school, to determine the level of development of these factors and their inclination to take engineering programs. The results become a fertile ground for the education system to intervene and organize teaching and training plans by the students' professional inclinations. For example, in this study, it was found that students quickly lose interest in engineering, even if they develop at a good level the factors they need to study it at university. In the same way, it is observed that they are not adequately advised, in the sense that studies oriented to know the degree to which they are qualified to access one or another university program are not applied. Therefore, most of them must be the ones who seek the program themselves, regardless of whether or not they have the skills to complete it and obtain a professional degree.

When comparing the factors of the student actor that have the greatest impact on their decision to abandon the study of engineering, with those found in the secondary school interviews, an ambitious goal that should be achieved by the institutions at this level, i.e., first identify the factors that students have more developed and structure support and counseling programs so that they take them into account when selecting a career, in this case, engineering. In the high school population, it was found that, in terms of engineering skills, logical thinking, and mathematical skills, students demonstrate a level that makes them good candidates to study engineering. But, for reasons that they cannot handle, they become disillusioned about pursuing these careers.

Limitations of the Study

Although the authors are aware of the work done and the effort applied, there remain some issues that could limit the results found:

1. The actors selected are not all those involved in the training process. Here we worked with people who dropped out of engineering programs as direct actors, taking into account, relational actors, universities, professors, and companies. However, actors such as the state, the family, or the global context are not involved. The reason is that the objective of the research is to find the factors that influence the decision to leave an engineering program, but which, as direct or relational actors, could be manipulated so that the next generation does not do the same. That is, by knowing these factors, a solution could be implemented to prevent new students from observing them as a problem for permanence in their careers.

2. The factors included in the application of the tools are not all those identified in previous research as causes of abandonment of the training process. The reason has to do with what was stated in the previous point, i.e., because not all factors can be manipulated by the assessors and, therefore, are not of interest in this research.

3. This study is descriptive, but the multivariate analysis is used, not to validate the theoretical model or to identify causal relationships, but with the idea of refining the bivariate analysis that may be needed; but, fundamentally, to find the relative strength of the associations between the defined factors and the dropout decision, taking into account the interrelationships that, with the application of such analysis, cannot be easily identified. Furthermore, while the multivariate results will be used for future research, they are not applied in this study to identify the general causes of student dropout.

4. The period under study covered the onset and development of the Covid-19 pandemic, which may have affected the students' decision about the research topic and, therefore, affected the results obtained.

6. CONCLUSIONS

Two investigations were conducted, on the one hand, to find the factors that have the greatest impact on students' decision to abandon their engineering studies and, on the other hand, to determine whether high school students are interested in studying engineering and whether they have developed the necessary skills to complete these programs. In the first, three tools were designed: online consultation, email surveys, and personal interviews, which were applied between 2021 and 2023 to first-, second-, and third-year engineering students. In the second, personal interviews were used with high school juniors, seniors, and juniors between 2021 and 2023.

After analyzing the information collected, the team concludes that to make high school students decide to take engineering courses and not drop out early, the actors involved must be aware that they can manipulate these factors and develop or innovate them, based on the fact that they have the aptitude to study these programs. In other words, the options for improvement start from 1) the need to structure and apply curricular reforms in high school and university; 2) more committed and trained teachers are required to teach courses to students of the new generation, and 3) companies should analyze their job offers and needs so that engineering students feel that studying and obtaining a degree in this discipline is important and has value in the environment.

Another issue concluded from this research is that universities, the media, and the state need to integrate with society to show the importance of engineering and engineers for the development of a country. In school, there is human capital with the potential to study these disciplines and shorten the gap between the supply and demand of engineers, because most countries raise their voices indicating the lack of these professionals. The education system should take advantage of the moment to integrate, in the training of students in school, principles of engineering education and potentiate the factors that these students have because they belong to a generation that uses and knows the technological developments of engineering itself. If we add to this the fact that in the future society will increasingly demand these products, then it is time to implement action plans to decrease the dropout rate in the university, while increasing the interest in taking these programs.

In short, reducing the dropout rate in engineering programs requires a willingness to accept that it is a serious problem that affects and will affect the development of the world in the coming decades. The priority is to identify candidates to study engineering as early as high school and seek to ensure that they do not become disillusioned with the various realities that confront them during their studies. If the students of the previous generation have already decided to abandon engineering, it will be quite difficult for them to return, but if structured plans are initiated now so that the students of the current generation decide to study engineering and complete their studies satisfactorily, the number of professional engineers in the world will increase in the next decade.

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XVI
Teaching and learning in the New Era: Challenges for teachers and students

Since the beginning of the century, Information Technologies IT have invaded and taken hold in classrooms, at all levels of education, and a pace that the education system could not have predicted. Because of this phenomenon, teachers face today, and in the future, increasingly challenging challenges to educate and train an increasingly connected and ubiquitous category of students, who access, use, and take advantage of new technologies in innovative ways, but, many times, without adequate guidance to improve their learning. This New Era in education requires teachers to keep their knowledge up to date and develop skills to use IT in their teaching model, design high-value learning outcomes, and leverage students' abilities for the benefit of their education. This chapter presents a series of reflections and proposals to help teachers teach, understand, and comprehend the new category of students, and to take advantage of IT to design better learning environments, both real and virtual. A *definition* of the new category of students and teachers in the New Era offered, and the challenges teachers face when entering the classroom, where new technologies are a common denominator, are described. In addition, some innovative strategies are proposed that teachers can use to achieve better learning outcomes while projecting training for a successful professional.

1. INTRODUCTION

Today, technological developments have *invaded* virtually every aspect of people's lives and, together with the global trends of the New World Order, are leading humanity into a dynamic new era of rapid and constant change, but full of uncertainties [1].

This new scenario calls for society to analyze the reality of the education system because the results show that students are not adequately trained to take on the challenges of the New Era. Complex problems such as global warming, migrations and inequalities, drinking water, energy, and social welfare exceed the capabilities of today's professionals, which makes us foresee a gray outlook for the coming decades. A joint effort is needed between governments, industries, academia, and society in general to define action plans and structure solutions in the short and medium term.

In these plans, it is mandatory to include the revolution in the education system because it has fallen short of responding to the demands, expectations, and capabilities of the new category of students, who were conceived, gestated, born, and developed in the digital era, have access to and master the technologies, have a greater awareness of the problems of the planet, are global, multidimensional and multicultural, have high expectations about the education they receive at school and are continuously challenging teachers and the system in general [2].

Meanwhile, teachers continue to educate them as in the 19th century, when they were taught on an assembly line to make them competent to work in factories and workshops. If the goal is to ensure that humanity survives the first half of the 21st century, more attention must be paid to the professional training of teachers, helping them to overcome the leftovers in the classroom and permanently improve their skills.

The revolution in the education system must begin now before students decide to abandon their education because they do not find answers to their concerns and abilities. This requires the structuring of an education and training system in which all the actors involved and interested in education participate, working harmoniously: students, families, the State, schools, teachers, the productive sector, and society in general. The objective must be to structure a curriculum around contents that stimulate students and provide them with the learning they need and deserve to develop learning outcomes to perform as professionals in the coming decades. This means revolutionizing the teaching model, the didactics, and the evaluation system, and offering a practical education that respects the students' learning model, with professionally trained teachers to achieve it.

2. STUDENTS OF THE NEW ERA

Students currently entering the education system were born amid the revolutionary technological developments of the past decade. On average, they spend between six and eight hours a day using new technologies for all purposes, including education [3]. This has led many researchers to consider that they are saturated with information that, more often than not, they do not validate before accepting it as true [4].

Others are multitasking students, because they can listen to and record music, watch, create, and publish content on the network, play video games, watch television, talk on the phone, and send messages, in addition to being active on social networks [5], with considerations such as those shown in Table 1.

Table 1. Activities to which the new generation devotes more time [3]

Activity	Characteristics that capture their attention
Video games	Challenger, dynamic, realism, practical, flexible, rewards, repetition, definition, supports, concrete, inclusive, motivating, cooperative, by levels, fun, relevant, intriguing
Internet	Share, read, consult, ask, know, movement, images, short texts, captivating
Decipher challenges	Short, real, concrete, eye-catching, feasible, with similarities, information, rewards, fun, intriguing
Solve riddles	Understandable, entertaining, fun, feasible, rewards, challenger, with similarities
TV	Fun, non-repetitive, movement, little dialogue, body language, hidden text (challenge), intriguing, suspense
Social exchange	Pleasant, using technology, other countries, with peers, shared interests, other cultures
Conversation	Familiar, pleasant setting, friendliness, rewards, current issues, solving concerns, being heard, role
Read	Short, images, attractive, colors, font sizes, current affairs, challenges, fun, rewards, meaningful
Crafts	Challenges, fun, movement, color, rewards, small, interaction, where possible with technology, current
Outdoor games	Fun, with pets, challenging, short, appropriate space, non-repetitive, non-fatiguing, role
Drawing	With technology, colors, movement, short, current

Likewise, and in general, they share characteristics such as:

- They prefer not to follow a set schedule or agenda and feel uncomfortable when they lose control when sitting in rows in a classroom to *learn*. They are ubiquitous and use IT to study at any time and in any order they want, i.e., they want to define the balance in what they do in their way.

- They do not like to be imposed on a method or a rigid schedule, because they want to be free to choose; they prefer to study through projects and use new technologies to work in teams, consult the necessary information, and be creative.

- Being exposed at all times to the world through IT, they do not want to isolate themselves at school, because they are social. When they meet in real reality they walk and have fun in groups, but in virtual reality, they prefer to identify themselves individually and join communities and peers around the world. They opt for collaborative work, share what they learn, and help others enter their worlds, but maintain their identity.

- They use the network to keep up to date and to search, on any site, for the information they require, following links to learn about various topics. In this activity, they learned to be tolerant of all people, regardless of their race, religion, and culture.

- They were born surrounded by technology and are influenced by new and continuous developments, which they see as tools to support much of their daily activities. Therefore, it is natural for them to use technology in their learning model and to experiment with new and diverse ways to take advantage of it. They prefer IT-mediated communication and have developed their language to express their opinions and ideas.

- They think differently and are not easily amazed, because, for most, technology is immersed in their lives. This category of students does not wonder, they simply accept life, adapt to it, and use technology, but they do not stop to look for details about the tools, because they are only interested in finding what they need, without any deviations.

- They do not stop too long to analyze the risks of their actions, because they assume them as part of their activities. They do not shy away from failure and try until they achieve their goals or until they realize that it is not possible to achieve them, then they reformulate their objectives.

- Because they stay connected to IT they learn about what is going on around the world, both positive and negative events. They developed different ways of valuing their free time because they see life differently; they do not share the idea of living life like their parents and decide what to do with their time, before having terms imposed on them that do not allow them to live it their way.

3. TEACHERS OF THE NEW ERA

To advise and accompany the formation and training of the new category of students, New Era teachers are expected to know, use, and innovate new technologies in the design of the teaching model. While IT generates changes in students, they are also expected to do so in the teachers who advise them. In general, and thanks to the new technologies, they should be better educated and trained, with experience in the use and innovations to the curriculum, because it is no longer enough to display degrees and diplomas, speak languages, or present papers around the world. After all, this does not *surprise* or *intimidate* students. What they want is for them to use all that to advise them and accompany their education and achievement of learning outcomes [6, 7].

Based on what is known about New Eralearners, today's teachers must develop new skills, abilities, and capabilities:

- To understand, understand and use new technologies and not resist learning about them, because most are reluctant to adopt and experience them, and are intimidated by what students know about tools they do not *want to* understand. This should be a task for faculties of education, in the sense of guiding the professional training of teachers to be bold, and daring, and not to be afraid of the unknown that can help them to attract and motivate students. It is time for teachers and students to work together in the classroom, sharing information, learning, and results to enrich the educational experience.

- Improve their self-esteem about their work, because although the system, institutions, and the State underestimate their work and professional development, they have to be aware that they have chosen a wonderful profession, but one that demands dedication and acceptance as people responsible for educating others. They must persist in their intention to educate people and train professionals, so they need to recognize the students and recognize themselves before starting a process for this purpose.

- Work as a team with people from all over the world and in a transdisciplinary way, because they need support and support to structure innovative curricula. The traditional *excuse that they* are not given the time to do so should not be the only reason for not doing so, because it only shows that they perceive their profession as static and that they do not require anything different from what they know to educate students. Although it cannot be denied that teachers require time to plan, they should be able to take advantage of their work in the classroom and do so, because it is there where they have the information, the data, the means, and the actors to make the teaching-learning process a playful one for all.

- Abandon their traditional comfort zones and let new technologies become part of their didactics and teaching model because IT has changed the role that teachers play in the education system. After all, they are no longer the holders of knowledge but advisors, facilitators, and tutors for students. They are no longer the authority or the only source of knowledge simply because they have degrees. After all, the student has access to information all over the world and in different languages, so this role conflicts with traditional models and does not allow learning to move in a practical direction.

- Be able to oppose the traditional system and use all the tools at their disposal to innovate it in the classroom and beyond. If the science of learning has shown that developing competencies is not the way to educate New Era learners [8, 9], then teachers are obliged to structure curriculum and content to achieve high-impact learning outcomes. While the education system and states are left to *impose* rules and regulations without practical and useful meaning, teachers have the authority not to accept them and adopt best practices to train people and train professionals for the New Era.

4. CHALLENGES FOR TEACHERS IN THE NEW ERA

It cannot be denied that the classroom, the school, and everything related to education changed in the new century: on the one hand, the new technologies and the new category of students and, on the other hand, the new jobs and the skills needed to perform them. In addition, the movement for innovation in curricula, teaching models, and the evaluation system was strengthened, which will necessarily lead to a revolution in the education system [10, 11]. The point is that the new category of students has become a triggering actor in search of changing the way education has been conducted since the nineteenth century.

On the other side are the teachers who think they are getting younger and better trained and prepared, but without sufficient support from the State to put their learning into practice. For this reason, they are immersed in tedious work on two fronts: 1) convincing students to enter the education system and to remain in it until they obtain a professional degree, and 2) training the people and professionals demanded by society, the world and the companies of the New Era. Therefore, as they seek to address these fronts, they are challenged by challenges such as the following:

- To ensure that learning outcomes are relevant to students and that their achievement is reflected in the improvement of their quality of life. This is achieved when students perceive that learning is practical because they can apply and experience it in real or virtual educational environments and that it is specific, concise, and fast. The challenge for the teacher is to make the information, which is widely accessed by students, relevant to meet their expectations and needs, otherwise, they will prefer to drop out of the educational system. Faced with the volume of information on the web, students do not feel the need to learn everything immediately but to be advised on how and where to find what they need, and how best to use it.

- Demonstrate to themselves and to students that IT can be distracting when there is no plan to take advantage of it and use it. On the one hand, new technologies facilitate communication, access to information, and the dissemination of ideas, but on the other hand, they are distracting tools that can cause people to become socially isolated. For this reason, and when they are integrated into the classroom, it is mandatory to have a plan so that students and teachers know how and when to use them properly and safely.

- Convince institutions to acquire new technologies because of the advantages they present for the curriculum, motivate students, and ensure the achievement of valuable learning outcomes. It is important to inform them that this acquisition can be costly, in addition to the need to structure implementation programs in terms of infrastructure, training, and technical support. These costs are recurrent, as is the need to train teachers to use them properly. It is of no use for the school to acquire technology that deteriorates and becomes outdated in the short term, and this is where the teacher needs the training to advise the institution as to which technology to acquire, how to maintain it, and how to update it.

- Avoid overburdening students in terms of schooling or extra-class work, with the excuse that new technologies make any task easier for them. The tradition in the education system is that each level blames the previous one for the students' deficiencies: primary education blames the families, secondary education blames primary education, university education blames secondary education, business blames the university and society blames the institutions [12]. Curricula, technologies, and contents are tools to be used by the teacher for the achievement of learning outcomes specific to each level. At one level of education, one should not overreach and try to cover topics from the higher level, with the excuse that the student is getting better training. While this may be a way to help students, it can become a double-edged sword. When they reach the higher level they do not find the challenges they expected, because they have already overcome them.

- Demand from the faculties of education an immediate updating of methodologies and the curricular use of new technologies and developments in the science of cognition. Universities, where teachers are trained, have to structure new models of education and training for these professionals, away from obsolete pedagogies and didactics. The reason is that in the New Era, these models do not fulfill the mission of educating people and training professionals, because students, institutions, companies, and jobs are different from those that existed in the 19th century. Therefore, it is imperative to revolutionize the education system.

- Overcoming the famous 30%, an indicator that the education system and the States apply for their justifying policies and methodologies [13]. According to this, only 30% of students succeed in formal education and graduate; another 30% drop out and enter informal education, where they are trained as skilled workers for the productive system; another 30% simply do not try and swell the numerous low-wage population worldwide. The challenge for teachers is to convince and motivate students to stay in the system, which is achieved with relevant learning activities, teaching adjusted to their learning model, and permanent and personalized attention.

- Advise, tutor, and accompany students from the moment they enter the educational system, to achieve a professional degree. Teachers should be the first to experience the content and learning outcomes of the courses because when formal education is not interesting for the new category of students, they abandon it for an education that quickly develops skills for the New Era, but without the personal and professional training, they require as social beings. In this century, uneducated people work just to make ends meet. They are not qualified to fill the new jobs because they do not develop a minimum level of communication, creative, interpersonal, and technical skills, nor a strong work ethic and personal integrity to succeed.

5. STRATEGIES FOR OVERCOMING TEACHER RESIDUALS IN THE NEW ERA

To motivate, engage, and effectively educate the new category of students, the education system must be revolutionized, teachers must be trained and professionally trained, and skills must be developed to take advantage of new technologies, with curricula designed to promote the collaborative, learning-centered work environments needed by students in the New Era. The goal is to educate the people and train the professionals needed for the survival of humanity in the New World Order.

The following are some proposals to help teachers overcome the challenges that the New Era has defined for them. These are not straightforward solutions that they need only follow literally to succeed, but rather feasible alternatives to implement in the changing contexts of education in the 21st century.

5.1 Bringing the right and necessary technology to the classroom

The education system, States, and institutions must ensure that the classroom has the technology needed to achieve learning outcomes. It is not a matter of equipping them with computers, projectors, interactive boards, and cameras, but of structuring a plan for their acquisition, implementation, use, updating, and maintenance to guarantee their permanence over time and for at least the academic period. Many states have high budgets to provide public schools with computers, but without planning for teacher training, infrastructure, security, and availability. In this way, students are demotivated, because the teacher ends up returning to the traditional pedagogy: chalk-board-speech.

5.2 Innovating the Curriculum

According to various researchers [14, 15], a quarter of students who have access to new technologies play network video games, dialogue with peers everywhere, access volumes of information, watch the news, disseminate what they know, help others, and learn about the world, among many other activities. Meanwhile, they are forced to go to school to study with static, obsolete, and demotivating curricula and content. On the web, there are hundreds of courses for teachers to be trained in the use and management of virtual reality, video game design, and other tools to innovate the curriculum and the teaching model, with the idea of capturing the attention of students and motivating them to stay in school.

It must be understood that the 21st-century classroom is attended by a new category of students, saturated with media, mostly with access to technology, and who have developed analytical thinking and teamwork skills, multitasking and problem-solving, who need an advisor to accompany them in processes of taking advantage of what they know.

The teacher should consider the following strategies as tools to innovate the curriculum:

- *Define appropriate and high-value learning outcomes*. The curriculum should provide students with a clear explanation of what they will achieve at the end of a course, as well as a precise definition of how to do it. The teacher should explain the curriculum, content, teaching model, learning outcomes, and assessment system to students in a way that creates clear, realistic, and achievable expectations of success. You must be aware that not everyone will achieve in the same unique way, at the same speed, or at the same time, but you need to make sure that everyone achieves under the same passing criteria. This forces him to diversify teaching, personalize learning, listen, and act as an accomplice, taking into account how each student learns.

- *Innovate didactics*. The curriculum needs to allow students to do each activity as many times as it takes to get through it, and the teacher needs to structure alternatives so that students try repeatedly, in different ways, until they succeed. This is similar to a video game in which the objective is to climb a cliff: if the first attempt is only halfway up, there is always the option to try again; if one attempt uses certain tools and still fails, the option is to select others until the top is reached. In the classroom, the curriculum and the teacher can structure something similar: allow students to complete parts of the activities and submit results for evaluation, then give feedback and allow them to try again, with other tools and another method. In this way, it is necessary to be patient, understand how they study and learn, recognize their times, and accept that their rhythms in the classroom are different.

- *Motivate teamwork*. Jobs in the New Era offer the opportunity to work together with people and machines to meet goals; some even require teaming up with individuals from other areas, developing collaborative processes that extend beyond industries. This can also be seen in the activities that students develop outside the school, whether playing online games, sharing ideas and knowledge, or helping others to overcome challenges. Faced with this reality, the teacher must design a teaching model using project-based learning, making students experience what they experience daily in video games or when surfing the net. The curriculum should include activities for students to integrate groups, recognize their peers, identify with whom they work and their areas of interest, and discover their differences as individuals. At the same time, arrange the classroom to develop collaborative work, exchange of ideas, peer evaluation, and sharing of experiences, learning, and mistakes.

- *Design learning outcomes of progressive achievement*. Learning is not achieved all at once but through levels, monitoring, analysis, and evaluation. The curriculum should be organized in such a way that students progressively move toward achieving the learning outcomes. The goal is for them to always identify clearly where they are in their achievement, where they are off track, and what they need to continue. They should be helped to see the big picture of learning, oriented to face the rest of the path to achievement, and advised on the tools and knowledge required. The teacher can use a video game as a reference, in which they must overcome stages until they reach the goal, emphasizing the skills they develop and how they can overcome difficulties with commitment and dedication.

- *Avoid monotony in the classroom*. An active and dynamic classroom keeps expectations and learning in motion and keeps students motivated to learn and experiment. Curriculum, content, and didactics should be dynamic, allowing the teacher to change the teaching environment and progress to new challenges as students achieve learning outcomes. A static, monotonous, and traditional classroom is demotivating, because the new category of students does not live that way, but are immersed in new technologies, media, and challenges that help them learn. Course content should not be an indivisible block, the teacher can divide it into projects that students develop and progress towards the achievement of learning outcomes while learning to manage time.

- *Provide timely feedback*. New Era students are fast, agile, and dynamic, so they expect teachers to respond in the same way. They are motivated to know promptly the consequences of their actions, in this case of their projects; therefore, the teacher must provide them with agile, timely, and useful feedback for their formative process. It is necessary to help them understand what is good in their work, what is useful to them, and how to direct it to the achievement of the learning results. But, in the same way, they must understand what is wrong, and what they must correct or discard because they need to verify that the learning is relevant to their lives.

- *Individualize teaching*. An error of the education system is to pretend that all students learn in the same way, at the same time, and in the same spaces, while the reality is that they are different and have different rhythms and different needs. The teacher must personalize the learning experience and advise them in the pursuit of learning; help them define achievable goals and identify the moments and points at which they may have difficulties. Although the criteria for approval are the same for everyone, the teacher must devise activities, procedures, and didactics that encourage them to work with dedication and to discover their strengths, preferences, and interests. In other words, give them opportunities to experiment, explore, make mistakes, and get out of their comfort zone.

- *Use logic and algorithms*. Education is logical and algorithmic, and every process must be planned and executed in order and with defined meaning, therefore, to achieve useful learning in students the teacher must coach them to be logical in what they do and want and to identify patterns in the complexity of projects. These strategies help them develop higher-level thinking skills, define better solutions, present better results, and better achieve learning outcomes.

By structuring the curriculum and content using these strategies, students feel integrated and in control to make their own decisions, work in teams, take risks, and define different ways to carry out projects, i.e., they learn to manage their learning. In the same way, teachers define clear rules in their teaching model, because they structure a self-directed learning environment, in which tasks are divided, decisions are made and they learn from experience. Table 2 shows a relationship between strategies, didactics, and curriculum innovation.

Table 2. Strategies, didactics, and innovation of the curriculum

Strategy	Didactics	Curriculum
Define appropriate and high-value learning outcomes	Diversify teaching, personalize learning, listen, and act as an accomplice, taking into account how each student learns.	Provides a clear explanation of the achievement, as well as a precise definition of how to do it.
Innovating didactics	Be patient, understand how they study and learn, recognize their times, and accept that the rhythms of the students in the classroom are different.	Allows each activity to be carried out repeatedly, using alternatives and different ways until success is achieved
Motivate teamwork	Design a teaching model using project-based learning.	Includes activities to integrate groups, recognize peers, identify who they work with and their areas of interest, and discover their differences as individuals.
Design learning outcomes of progressive achievement	Define activities in which stages are overcome until the goal is reached, and emphasize the skills they develop and how to overcome difficulties.	Allows progressive progress towards the achievement of the learning outcomes.
Avoiding monotony in the classroom	Break content into projects to develop and progress toward the achievement of learning outcomes.	Dynamic content and didactics allow the teacher to change the teaching environment and progress to new challenges.
Timely feedback	Provide agile and useful feedback for the training process.	Helps to identify what is good, what works, and how to direct it to the achievement of learning outcomes
Individualizing education	Define achievable individualized objectives and identify moments and points of difficulty.	It respects the fact that students are different, learn at different rates, and have different needs.
Use logic and algorithms	Using logic to identify patterns in project complexity	Develops high-level thinking skills

5.3 Ongoing self-training

Bringing the right and necessary technology to the classroom and innovating the curriculum do not achieve positive results in learning when teachers are not trained to do so and manage it. Hence the importance of ongoing self-training to guide and mentor teaching processes that lead students to achieve valuable learning outcomes. Instead of faculties of education prioritizing the learning of English as a degree requirement, they should be concerned that students develop skills and abilities to keep their body of knowledge up to date and require them to be skilled in the management and use of new technologies.

New Erastudents expect their teachers to be prepared to advise them, with innovative didactics and the necessary knowledge to seamlessly integrate IT in the classroom.

However, developing training and self-training programs is not enough if we do not take into account that the inclusion of new technologies in the classroom should be valuable to improve the professional development and collaborative work of teachers. Various institutions claim that technologies shape the learning environment, but they are only an instrument for students and teachers to come together and learn about the world and its problems. Reality shows that a professionally trained teacher with structured self-training plans is not distracted by IT because he or she has the appropriate training and time to innovate his or her teaching model, improve the curriculum, and coach students to achieve learning outcomes.

5.4 Recognizing students

The teacher must understand and comprehend the individuals who accompany them in the classroom, identify their cultural background, their level of access and use of new technologies, their needs, and expectations, what they know and what they need, as well as why they are in school. This allows you to structure a teaching model in which each student is recognized as an individual and as the center of learning, and they develop updated and relevant skills for the New Era. In addition, it is a good way to ensure that everyone is trained and empowered to learn for life, rather than worrying about numerical assessment on standardized tests.

6. CONCLUSIONS

As society realizes that the new category of learners is a unique population, the education system will have to revolutionize itself and structure better educational practices to train and empower them. New technologies are extraordinary tools that in this century shape and enhance learning environments, but the actors in the educational process must develop digital literacy skills and use them to complement, not replace high-quality teaching models and didactics.

As tools for education, Information Technologies cannot be more important than the interaction, real or virtual, between students and teachers, they must only be understood and used to configure a learning environment in which New Erastudents feel comfortable, motivated, and challenged.

On the other hand, teachers have the obligation to recognize students, innovate the curriculum and the teaching model, and self-train themselves to understand the language, the learning model, and the use of new technologies that students have, this will make them great models for them, as well as trainers of people.

If the need for highly qualified professionals persists in the current decade, in the New Era it will be a major problem that could limit the development of humanity. Aware of this problem, companies have initiated programs to hire highly qualified workers and to retrain them permanently according to the skills demanded by the economic-productive context, a role that should be assumed by the education system, but which still seems to be unaware of the problem.

Schools must partner with businesses and governments to innovate curricula and content, the industry can help build talent pipelines and mobility across sectors, and governments must strengthen education policies and safeguard education as good for humanity. In this way, society will prepare for the New World Order, while students will develop the skills needed to lead the changes ahead.

Although several technological revolutions have taken place in the first decades of the 21st century, society expects the education system to be revolutionized, to train and qualify teachers to advise the new category of students, and to help them overcome the remains in terms of improving the education of people and the training of professionals.

While the industry grows and innovates to meet the needs of the globalized world, education, beyond some isolated efforts of enthusiasts, remains stuck in an obsolete model that does not match the New Era, let alone the global context of the coming decades, the challenges of teachers and the needs of students.

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XVII

Evaluation of the reality of the teaching of mathematics in higher education in the 21st century. Case Study: Engineering programs

The myth of mathematics is that the future of humanity depends on the privileges that have higher abilities in them. The reality is that currently is difficult to find somebody to perform professionally and be efficient in his work using something else than an electronic paper and the mathematics of the high school (arithmetic and some algebra, statistics, and programming). On the other hand, the development and use of the areas of Information Technology IT have transformed the companies' engineering specialties and needs, and have created opportunities in related areas, such as in the way in which acquired or develop the abilities of their students, as the way of applying them. This new scenario presents a lot of debate about what mathematical abilities must be developed by the engineer, how and when to teach them, and if all disciplines consider engineering needs the same volume. To contribute to this debate, researchers performed collaborative research to answer some related concerns, especially to determine the need for mathematics in higher education on engineering.

1. INTRODUCTION

The myth of mathematics is that the future of humanity depends on the privileges that have higher abilities in them. This myth goes back at least to the decade of the 60 when Russians exceeded the North Americans in the space race because they were better in mathematics and science, or when Germans and Japanese did it in the 80. Today the question is with the Indies and Chinese because for many they are better in mathematics and science. The reality is that currently is difficult to find somebody to perform professionally and be efficient in his work using something else than an electronic paper and the mathematics of the high school (arithmetic and some algebra, statistics, and programming).

A question very different is the mathematical abilities that must own who work as scientists and engineers, and how much mathematics needs [1]. But it reduces this number that most of them just use electronic paper and mathematics in high school. This suggests that a wide percentage of the jobs in which is require advanced degrees are using this requirement just like a filter. In the world exists a reality that cannot be hidden and that has been researched by diverse authors: if it is the task currently performed the most by engineers, graduates of the faculty of engineering of several countries around the world, the average of those that occupy in engineering step of management, administration, directing, teaching, or advice is inferior to 20%, and, possibly, to 10% [2, 3], which means that just a few of them could be using a little more of mathematics that the vast majority.

Too many defenders of the extensive curriculums in mathematics in the university this is a conjecture that needs to be solved with solid statistics and depth demonstrations. That is why the content presented here is based on numerous data collected through interviews with scientists, engineers, science professors, engineering, and mathematics in a research shared whir researchers from MIT, the California State University, and Instituto Antioqueño de Investigación. The point is that this conjecture would accept revolutionary educational implications. In particular, it would undermine the legitimacy of demand to students the approbation of a large number of mathematics courses to be able to graduate, just because are studying engineering and so should be. This quantity of mathematics is just really needed by a small fraction of the workforce in this discipline. The arguments that are brandishing to defeat this volume of mathematics are that:

1. Mathematics is fundamental for a serious higher education. This may be true because understanding, analyzing, and solving some engineering problems requires solid logical reasoning. Unfortunately, this kind of professional is just a fraction of the number of high-education graduates, and still, the educative system is reasonable and viable and insists that all engineering students have to receive that level of education. Of course, that must be in the curriculum, but just for those who need it. This cannot be generalized to this need, we are no longer in the industrial era when all the students had to be competent in everything; today reality is different because engineers need to develop other skills, abilities, and capacities that depend on their specialty.

2. Mathematics helps to think clearly. Valuations of respondents in this respect are very low, and most consider it a folly. In sports exists a concept about the abilities: if want to improve your tennis game, do not practice baseball. The same can be said about intellectual abilities, because, in any case, the transference of mathematic abilities is not directly proportional to the volume of courses. On the other hand, mathematics is of little or no use in most of the problems in ordinary life [4].

All this would be more beneficial to engineering professionals and universities to develop those abilities, skills, and capacities to understand the world as a logical vision [5]. Rather than stuff them with several mathematics courses that neither develop their logical reasoning, because they are oriented to memorize formulas without meaning nor help them to be truly logical because mathematics logic is provided without practical guidance and camouflaged within such formulas. Mathematics is necessary, but just for those who needed, it or want it; and, with security never would be required in that volume of all the students [6]. This chapter has described the results of the research that support the above statements.

2. METHOD

An online survey was designed to apply to students, professionals, educational administrators, employers, and engineering-related organizations located in the United States, China, Germany, India, England, Japan, Colombia, Norway, and Australia. Responses were received from 345 entrepreneurs, 1650 engineers, 2540 students, 65 universities, and 33 engineering organizations. The invitation to participate was sent via email. 100% of the population is related to some engineering activity and the sample was selected from a database obtained with the collaboration of the United States Association of Civil Engineers.

The collected information was analyzed by applying variable crossing and direct correlation between the sought and obtained results. Because the volume of data exceeded the capacity of the analysis group, it was decided to structure them using a conceptual approach matrix, that is, a central concept was defined around which the data should orbit. In the end, those closest to the axis of rotation of the concept were selected and the final analyses presented below were made with them.

3. RESULTS

3.1 What is engineering?

This is a question of debate that rotates around contradictory definitions of what is an engineer because exist different conceptions of this profession not just among countries, but also inside them. In the academic and professional ambit, an engineer is defined as a person capable of using scientific knowledge, especially in mathematics and science, to resolve problems in the real world. However, this definition difficult to inventory the engineering population, because it is not clear how many engineers do that. Diverse study and information use multiple definitions of engineer, like as a person who works in the occupation of engineering; an individual whose more recent grade is founded in a traditional engineering discipline; or a person who works in a position that requires specific engineering knowledge [7, 8].

On the other hand, traditionally engineering has been divided into specialties, such as civil engineering, mechanic engineering, electric engineering, and so on. Although in the last decades, disciplines such as Computer Sciences CS and IT have increased their popularity in the world, academic institutions in the United States are divided about whether these specialties must be affiliated with the engineering faculties, and rarely award degrees for them. But most countries, especially Latin-Americans, automatically are linked to these faculties just because sound very harmonious with the last name engineering [9].

Although important universities of the United States offer degrees in Computational Science areas through its engineering faculties, hundreds of others offer them outside of them and especially link them to arts and science faculties. These distinctions make it much more difficult been able to define and distinguish engineering as a scientific knowledge area. While, in the Latin-American countries and China and India, these professionals graduated from the engineering faculties, and most institutions represent the highest percentage of graduates. The reasons for these differences are that in these countries the education in areas related to computers is much more economical than in engineering as civil or mechanic because share the call common courses to this, among them mathematics, although due to the profile of graduation does not need it to their professional exercise.

Besides, some countries face difficulty in determining what or who have been considered engineers. For example, in the interviews in China for this research was noted that the model of soviet development provides them with advisers that set the term engineering in many institutions and programs related to science and technology, but that necessarily does not have contents of any engineering. The legacy of this system means that some engineering programs will not be able to educate or even graduate real engineers. After being evaluated carefully the educative picture of engineers, in disciplines that to others are not engineering, is taught and measured with the same metrics that in traditional engineering. It means engineering is engineering although does not be engineering. Therefore, its planes of study are oriented to develop abilities, skills, and capacities for problem resolution fundamentals from a solid mathematics education.

Besides, a qualified individual under these conditions is at the center of the current debate about the pertinence of engineering programs and the crisis that lives this area of knowledge in the world [10].

3.2 Mathematics and Engineering

The role of mathematics in engineering teaching is a matter of old data, when in the industrial era was determined that workers would engage quickly in production lines, assume their new role as workers, and forget the hunters-collectors, was necessary that see the world from the optic of the logic and the abstraction. This strategy worked for them many years later. But in the change of era and the emergence of the new society and ways of production, that strategy has to be rethought. Recently there have been discussions about what mathematics abilities are necessary to engineers of this century, how and when teaching them, and how much of it is necessary.

Then a change of the century and technological development allow the emergence of the digital era, in which abilities, skills, and capacities to use those develops must be the tip of the iceberg for engineering curriculum. Traditionally is accepted that mathematics plays a main role in the formation of the engineer, as a requirement of entry as a fundamental basic element in their curriculum. This role has been a subject of high profile for many years but lately has stimulated the debate about whether to problems of Information Society should maintain its current. The imperious need to recruit and retain the students in the engineering programs means that is natural that academics focus on the problem of mathematics because it is the principal factor of dropout and grade overdue for students. However, the role of mathematics in professional practice has radically changed in this era. Today, mathematics is perceived as necessary to engineering, but fundamental just to certain kinds of engineers, not as a general rule.

To resolve the educative contradictions about whether mathematics is transverse to all engineering or otherwise just must be emphasized in some programs is necessary to take into account their different uses in the engineering practice: the direct utility of the techniques and practical ideas to understand and resolve complex problems, the indirect as an element that contributes to experiences and judgment develops. In the first case mathematics is and will continue crucial, but in the second is optional depending on the interest and the aptitudes of the student. That is why it is necessary to conceptualize several questions that face engineering education:

- What kind of mathematics knowledge is needed by the engineer?
- Can we measure the level of mathematics knowledge that needs an engineer for his professional performance? What is the base of this measure?
- How do the new developments in IT the picture of mathematics?
- When, how, and how much mathematics must be taught to engineers?

In this regard and since the introduction on a large scale of the areas of IT in the engineering practice in the decade 1980, the profession came into a long period of transition related to the need and pertinence of mathematics. Some aspects of them remain more essential than others that have changed considerably with modernism. In the middle is found a large zone of transition, where the limits between relevant and irrelevant are changing, but not in the same way as all the engineering.

A generalized consensus in the profession about what is considered a mathematical ability desirable from an engineer: mathematics should inculcate the discipline and rigorous thought to develop arguments based on the supposition and simplification, and, about all, convince students and the industry of their value as a tool of which can call on when it is needed quantitative evidence to support an assertion, hypotheses or physical intuition [11]. Although few disagree with this description, persist many doubts about the real contribution of mathematics to all engineering, and even more, about what mathematics is.

The practice of the real engineer does not tend to consider them as a problematic area, or something that has to deal with just because. Many academics consider that mathematics is crucial to most engineers, especially because required to develop a balance of abilities along their training process that allows them to practice the profession. But the industry does not generalize in the same way, because requires them to perform in different positions and with different roles: consulters, advisers, project designers, department bosses, analysts, or managers were just required between the 5% and the 10% of mathematics knowledge received in the program.

During the Industrial Era, engineers had to learn much mathematics for practical purposes. At the same time, were expected that develop some mathematical understanding as a logical form of think and give it importance as part of their practical experience. The availability of the computer as a calculation tool has undone this relationship between the theoretical and practical aspects. The teaching of practical mathematics and oriented and applied has become at the center of the needs of some engineers, which by direct relationship should give as a result a variation in the number of courses of the same.

This does not mean that mathematics must be abolished from all engineering programs but should find a proper balance in the curriculum. If engineering specializes and modernizes, also should be doing the contents and the didactics to teach mathematics, as a way to think prospectively and answer to the professional needs of the engineer. Another complex matter in this discussion is whether mathematics is the only tool that allows developers logical reasoning. Because if it is, all the disciplines should have them in their curriculum, because in this century it is not possible to conceive a professional without this capacity. Besides, all need it to be able to understand and solve all the complex problems that represent the Information Society and New Era.

The problem of the gap between the needs and the mathematics reality of XXI century engineers is a preoccupation that should interest all the disciplines that appreciate engineering. According to all industry managers who participated in the research, the students who are training with the current curriculum lack of abilities and analytic powers to analyze and solve complex problems, and do not achieve a proper appreciation of mathematics in terms of functions of precision and test. The engineer who participated in the research that originates this chapter accepts the fact that this plan does not offer them the necessary for their professional performance, although the volume of courses is maintained unalterable, and claims for important measures to reform them.

On the other side, inquiring about the perceptions of employers about the importance of mathematics as a distinctive characteristic of a good engineer was found to them was a matter of minor preoccupation because their needs are for engineers that understand guidance and develop the joint task. That is why we do not see the need for graduates to have a holistic consciousness of mathematics.

Although some institutions have conducive spaces and discussions to achieve a solution to this situation, the research found that most remain dominated by the directress of the faculties in science and mathematics. Many engineering deans argued that in their programs it is impossible to participate in the structuration and formulation of the related courses because those faculties handle of design and serve them, with total un-knowledge of the needs of the students and the same programs. The solution here, which for example has already begun to be implemented at MIT, is that the programs of engineering indicate to the faculties of science what mathematic content is needed for each discipline they offer. If this were possible, the engineer would not receive only mathematic preparation, as was done in the Industrial Era when were prepared professionals for a unique line of products, but would receive mathematics oriented to their profile.

On the other hand, the industry of IT has revolutionized the use of analytic techniques in engineering practice. Recently they have begun to make profound changes in the work offered in this industry because their needs are different from any other in which are required, professional engineers. Moreover, many of their work offers do not require traditional engineers, but a new kind of professional with abilities, skills, and special capacities to unfold in a global immaterial world. Something which is not availing the mathematics that is taught in engineering. In this set, the results of the research prove that universities and governments still have not perceived the problem.

Questioning educative management and the control organism about whether at the moment of design and approval, the opening of new engineering has into account the impact on IT and the new needs of this industry, the answer was unanimity: Yes. But when was consulted about the offer of programs in different countries, especially in Latin America, was discovered that it is not true at all: the names of the programs were confusing; does not exist any direct relationship between the denominations, the contents, and the curriculum; in general terms are a bad copy of the traditional engineering, whit small variations in the names of the courses; are foreign to the global needs, and, even worst, to copies of each country; and all the programs have the same base, the same quantity of courses, the same contents, and the same evaluative principles to mathematics. This shows clearly the affirmations of the engineering deans, in the sent those sciences are who domain this matter.

4. DISCUSSION

Do engineering professionals need and use the level of mathematics with which they are trained? In this debate emerges the question if all engineers should be educated in the same way and with the same resources and contents. This is not just about statistics, although are fundamental to the discussion, to achieve the comprehension of a matter much more important: How many graduates, properly entrained as engineers, need the current volume of mathematics to satisfy the national and global demands? The answer to this question should be approached from several perspectives:

1. What kind of engineers are currently graduates? Defining and measuring issues of quality is difficult, for conceptual reasons as empiric. Currently are presented discussions inside the profession of engineering which redefined the abilities that characterized a high-quality education and argued the best way to inculcate them through education equally quality. This research was conducted through interviews with analytics of the industry and with academics to develop a typology of work that engineers could perform. Identify two types of ideal graduates in engineering that represent the materialization of that spectrum of skills, necessary to develop and *the support* necessary for the economy.

   Entrepreneurs are individuals who develop logical reasoning and abstract thinking that trains them to resolve problems of a high level using scientific knowledge and are more likely to generate innovation. Work in a team, have strong interpersonal abilities and can translate engineering technique terminology into a common language to all people can understand; tend to be competitive on a global level, and have demand, especially in the developed countries, regardless of their location. Therefore, need a solid education in mathematics; but, comparatively, represent a low percentage of the real needs of science and the industry. In contrast, the support engineer owns a solid technique formation, but not the experience or the knowledge to apply repetitive works that do not demand wide logical reasoning and much less solid abstract thinking. Represent the labor force that needs economic development, and therefore adjust perfectly to work offers.

   If these engineers perform this work, and if are the most wanted by the industry, why must be educated in the same way as the entrepreneurs? In the developed countries was understood decades ago that have distinguished, engineering faculties decided to move these programs to other faculties in which contents in science and mathematics adjust better to their realities and needs. This way it is obvious desertion and graduation stagnation are the cause of the not-approbation of the mathematics courses, and offer the qualified and trained professional that mostly needs the industry and the economy.

   Empirically is difficult to separate one from others to an individual level, because the current education system is based in large part on the call competencies. While those who graduated from first-level universities, with robust programs of research and with innovation trajectory in plans of internationalization, have more probability of being entrepreneurs, this cannot be a rigid distention. Because the graduates of these institutions can be one or the other kind, depending on their real formative intention; and the other institutions can develop (or learn quickly) the necessary abilities to compete at a global level, which also depends on their interests and aptitudes. The same applies in the case of the countries because any can say that has the monopoly of the best engineering faculties or the excellence of graduates. So, while this typology does not offer a statistical breakdown infallible of the quality of the engineer or the related employability, is useful to show that mathematics should not be taught in the same that in all the programs in the engineering faculties, because can that many of them not even be real engineering.

Another important finding discovered with this research is crescent evidence that this dichotomy is directly related whit how are conceived the companies to these professionals and how try to educate them in the universities. This topic surveyed 498 businessmen from all over the world whose industries are transactional and are involved directly with some engineering discipline. Were asked to compare the productivity and the quality of the performed work at the national level with performed foreign, to know the strengths and weaknesses points of their labor force in engineering.

From their answer would be able to derive knowledge about the characteristics of their entrepreneur's engineer and the support. The first tend to have a good technique formation, besides a not-technique field; often are more creative and have better business abilities, but at the same time, demand higher salaries and search new challenges to demonstrate that able to perform superior level work. The second, on the contrary, can domain the fundamental concepts of their disciplines, of project management, and can relate to other functional disciplines. These individuals, however, are less susceptible to solving complex problems or providing innovative results.

On the other hand, the comparatively global low demand for an engineer who combines abilities, skills, and capacities that go beyond traditional engineering with a good education in science, is highlighted in diverse empiric studies [12]. The reality is that, comparatively, the industry needs a higher number of support engineers.

On the supply side, professors and management of the faculties of engineering consulted also are trying to graduate new types of engineer, in a try to answer to the challenge of a workforce of engineering each time more global. For example, some try to integrate fields such as economics and rights with the basic principle of engineering, to help promote abilities more advanced innovation, a better spirit of an entrepreneur, and high technology management efficiency [13].

Others claim that the preparation of the next generation of engineers to entry in this new globalized world with a competitive advantage requires inventiveness, resources, and a continuum evolution of methods and didactics to instill in parallel the intercultural communication, the global management of resources, and the professional interpersonal formation with the technique related topics, necessary, and not-negotiable of the discipline [14, 15].

This must not be confusing with the generalized practice in universities and Latin American governments, where offer and approve any program like engineering, just to achieve several students that give them sustainability, but whiteout analyzed the realities of their economics and the global trend. What if, when considering engineering, the number of courses, the graduation demands, and the contents in mathematics are not negotiable?

2. What is the level of competitiveness of engineers in the global economy? To assess the quality problem first is necessary to search metrics that allow a balanced comparison of the engineers

of the different regions and countries. However, this comparison is not an easy task. As has been indicated, defining an engineer of quality is a topic of debate around the world, but is even more difficult to achieve an international consensus about the characteristics of the competitively high quality of an engineer on a global level. In the second place, the role of the engineer in the economics of the countries cannot be standardized, due to the different levels of development in each one.

The qualities that would make an engineer in a developing country are not enough to get a job in one development. All this makes that difficult to perform transnational comparisons; but what was found in the research is that is much easier to be able to match skills, abilities, and mathematics capacities that owned an engineer for the world. The conclusion on this point is that is not required that be a scientific genius but an engineer that perform efficiently and efficacy the work for which was hired, it means, the mathematic level is irrelevant to most of the organizations consulted.

However, the matter of competitively was addressed in this research from an analysis of the results of a survey conducted on 208 companies, which was wanted to measure the employability, and therefore the competitively, in the global labor markets of engineers in a variety of countries. In this work were consulted among professionals with a degree in engineering recognized worldwide, from which country would be willing to employ. Because we used similar criteria of employment, it means, each company evaluated its possibilities according to its own needs, was able to perform an equitable comparison between the global competitively, and therefore, in some grade, of the quality of the wanted engineer.

The results indicated that 40% preferred to graduate from the United States, 24% from India, 15% from the Japanese, 11% from the Chinese, and 10% from Latin America. The barriers to employability more outstanding refer to the quality of education, the cultural problems, and frequently the lack of accessibility to technological resources. The domain of English is a concern to all companies, but at the same time does not impede to acceptance of a graduate engineer. The most important to 94% of the respondents is that the engineer owns the skills, abilities, and capacities to develop the task effectively and efficiently. A parallel question that was included in the survey was if the level, quantity, and notes in mathematics were a distinctive sign, and the 100% answer was not, because the real need was professional with very good bases in IT.

3. Does there exist a relation between the qualities of the education whit the quantity of the mathematics in it? Quality and quantity are tightly linked in many questions of engineering. Wanting to improve the quality of education to increase employability often are divergent strategies. Improving the quality means dedicating more resources to the student or improving the efficiency of those resources, while an increase in the quantity means that exists a greater number of students; which under the fixed assets means a decrease of the same for each student. The grade of quality cannot be easily maintained when the goal is to expand the student population, at least the academic staff, the facilities, and the resources gowns in consequence. In many countries, both developing and developed, private institutions are a call to fill that void. Unfortunately, the variations in the infrastructure, the funding, and the result of the teaching quality in the education system are incompatible in many of them [16].

   Besides, the quality of the private institutions in most countries varies significantly. The funding, the facilities, the teachers, and the quality of student recruitment are their principal concerns. For example, some efforts to retain the number of students for the duration of a program, but desertion is very high due to the economic difficulties to give them continuity in their studies. In the interviews that were conducted with education, officials found that some institutions end an academic course with fewer teachers than those that started, due to the student's desertion. In consequence, the quality of the education suffers because the courses must assume teachers who are not truly entraining to advise them. In the countries in developing very few of these institutions have economic incomes different from tuition, which must sacrifice educative quality criteria to have several students that allow them to continue in the business.

As was found in this research, many students perceive private universities as facilities, because they do not make a lot to maintain quality standards it is relativity easy to achieve the title; likewise appreciate them as walkway universities, because the students seem like models that parade in their corridors in search of a degree. Doing it argues that is necessary to limit the increase of enrolled and maintain just those that can attend programs of global quality. The quality of education in the universities of the first level is probably the decisive factor in employability because companies search for graduates in engineering.

Another matter is the perception of the relationship between the quality of education and the quantity of mathematics in the programs of engineering. To businessmen, this is a question of whiteout transcendence to employability, but laboratories and research centers are the predominant factors. The respondents reproach the fact that in disciplines in TI, that do not classify as engineering, the curriculum is the same as traditional engineering and recognized globally. To them is preferable that this time be dedicated to courses in which to develop in the student the abilities related whit their program, which improves their competitiveness and employability. Some consider it absurd that a student delays one or two years of their graduation because cannot approve a mathematics course that will not serve him anything as a professional. On the contrary, laboratories and research centers are important a solid formation in mathematics and science, because to solve their problems needs an entrepreneur's engineer.

5. CONCLUSIONS

The students of engineering programs complain that they do not need certain courses of mathematics in such a quantity, because their goal is not to be scientific much less mathematics. Do not request the elimination of this knowledge area, that allows them to develop abilities, skills, and capacities to be successful professionals. The research that originates this chapter was to investigate if we conform with the mathematics received in their programs and just 10% answered affirmatively. But when those were asked about their future as professionals they see themselves as research scientific and innovative. On the contrary, 90% said that not, they see themselves as an engineer who attend the social needs through the resolution of everyday problems.

The reality shown in the results of the research is that all engineering programs do not need the same volume or the same contents of mathematics. The specialties that originated the IT industry development, the need in all the world for a support engineer for economic development, and the prevailing failure of logical reasoning are essential elements to request a mathematic oriented, and that the curriculum involved just the required quantity to each specialty. Besides, if this is not possible, then means that the program that is been analyzed is not engineering, and must be translated to a faculty that demands to be a minor in mathematics.

The contents of the mathematics courses must focus on solving real-life problems, exposing the students to abstract tools, especially in the manipulation of unknown quantities. But there is a world of difference between teaching pure mathematics, whiteout context, and oriented to pertinent problems that lead to appreciating models and mathematic formulas to clarify situations in the real world.

The businessmen survey agrees that professionals come to their jobs with a universe of knowledge, but unknown how to use it to answer the needs of the context in which work. Many attribute this that education systems have adopted a formation by competencies, which is deteriorating the abilities, skills, and capacities that engineers need to perform successfully in real life. Because are competent, but do not reason. It means, were educated to perform in a line of products to answer statics labors, not to act in multidimensional, transdisciplinary, dynamic, and complex scenarios of this century.

Then, how many mathematics needs the engineers of the XXI century? For decades, business leaders, educators, and politicians of the XX century have argued that students of engineering must be taught the most advanced levels of mathematics. All felt worried because of the competition and the shock was the shortage of professionals trained to exercise the engineering and other fields of high technology, with the argument of that one economic as then still the jobs of minor range required good levels of mathematic competition. We're convinced that all the engineering programs, being such, needed the same quantity of mathematics to achieve the competencies that the industry waited for from them.

That was then, although is a situation that does not differ a lot from what manifests the conservatives of the essence of mathematics to current engineering. But the situation has to change because the matter is that currently, somebody is wrong: many of the programs offered as engineering are not engineering, and mathematics is no longer the philosopher's stone to educate engineers. Because, as manifest by the administrators of the transnational companies involved in this research, the myth that engineering is nothing whiteout mathematics is a matter that no longer scares anybody. Today is needed professional engineers think before acting in real life, not levitate in the middle of mathematic formulas and tele-transport to another universe to find some solution to problems planted.

The development and the economy in the current world need practice engineers, skillful quickly in answering, and that support whit teamwork. Engineers that in everything see science and pure mathematics are needed in the labs and in the research center, where the work is mostly individual and interdisciplinary. For all this is necessary to rethink the mathematics in the engineering of the 21st century.

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XVIII
Impact of the interactive teaching model on learning outcomes in virtual education

The objective of this study is to determine the impact of interactivity and the teaching model on the achievement of student learning outcomes in a Computer Science course at a Colombian university. The types of interaction analyzed in this research are teacher-student, student-student, student-content, and student-technology. Several learning activities were designed and implemented for each of the interactions and a formative evaluation model was used to measure the achievement of the learning outcomes. According to the quantitative results and through regression analysis, it was found that students who participated interacted effectively in the learning activities and achieved comparatively better academic results than when participating in face-to-face courses. The quantitative analytical results demonstrate that student-student interaction has the greatest impact on the achievement of learning outcomes. The findings in this study can help teachers to improve the design of their teaching and assessment models and to move away from their role as the oracle of knowledge.

1. INTRODUCTION

In Decree 1330 of 2019 the Colombian Ministry of Education [1] emphasizes that:

> ... taking into account that currently the Quality Assurance System of Higher Education is focused on the evaluation of capabilities and processes, it is necessary to strengthen it by incorporating student learning outcomes, conceived as the express statements of what a student is expected to know and demonstrate at the time of completing an academic program. That such statements should be consistent with the need for comprehensive training and with the dynamics of lifelong learning, necessary for a responsible professional and civic practice. Therefore, it is expected that the learning outcomes are aligned with the graduate profile established by the institution and by the specific program.

In other words, universities should adopt an educational approach based on learning outcomes [2]. A proposal that is based, among other things, on the advantages offered by Information Technologies IT to innovate education, so these reforms intend to use them to improve the quality of education, based on students achieving specific learning outcomes, which will serve as evaluation criteria to academic goals.

One of the objectives of using IT in education is to help improve students' learning outcomes by assessing the criteria by which they achieve academic goals. Traditionally, in the education system, two forms are applied to evaluate students' academic performance: summative evaluation and formative evaluation.

That is an evaluation of previously defined results through periodic exams and an evaluation at the end of the course of the results estimated for the learning process. These evaluative mechanics generate challenges for teachers about how to design a teaching model for students to better achieve the learning outcomes because it is not easy to structure a template for each course and each expected learning outcome.

On the other hand, some authors have focused their research on understanding and comprehending the different factors involved in the achievement of learning outcomes [3]. The study by Zacharis [4] aims to develop a practical model to predict the risk of students' poor performance in courses. The author suggests that analyzing data stored in learning management systems allows teachers to develop timely evidence-based interventions.

According to Hoque [5], learning domains can be categorized as cognitive (knowledge), psychomotor (skills), and affective (attitudes), and it is up to the teacher to implement an effective teaching model for students to achieve the stated learning outcomes.

For Ping et al. [6], there is a wide variety of factors that influence the achievement of learning outcomes and, based on knowledge conversion theory and marketing concepts, they analyze two important antecedents: teachers' knowledge transfer and students' orientation. They found that knowledge transfer plays an important role in students' learning and achievement of learning outcomes, furthermore, that the guidance provided to them by the teacher influences such learning, and that students' prior knowledge has a positive moderating effect.

Likewise, other research is oriented to analyze factors related to pedagogical [7-9], content [10, 11], teaching model [12], student motivation [13], and teacher quality [14, 15].

The reality is that when students participate in virtual education, they spend most of their time doing online activities or interacting with the system, so learning outcomes depend on many different factors. Other studies show that interactive activities are one of the factors with the highest impact on learning outcomes [16-18]. However, finding and defining the interactive activities that most influence learning outcomes is still an important area of research. It is because of this that one of the aims of this research is to determine the specific interactive activities and the extent of their impact on student learning outcomes. In addition, an assessment model is proposed to help teachers and institutions predict learning outcomes so that students can better achieve them.

2. FRAME OF REFERENCE

To achieve the objective of this research, the authors conducted a literature review in search of information about the most important issues to consider about the achievement of learning outcomes in virtual education. This search was defined from the following aspects: virtual education and learning outcomes, and interaction in virtual education. The following is a description of the results from the analysis presented in some representative research.

2.1 Virtual education and learning outcomes

Based on the assertion that many studies show that, in virtual education, factors such as course organization and structure, student participation and interaction, and the teaching model account for significant variation in student satisfaction and learning outcomes, and that research has yet to find a satisfactory relationship, Gray and DiLoreto [19] researched virtual education and the variables that influence student satisfaction and learning outcomes. Among other things, they analyzed the relationships between course structure/organization, student interaction and participation, and the teaching model, to find how to improve learning and the quality of virtual education.

Surjono et al. [20] developed a quasi-experimental study to discover how virtual activities influence learning outcomes. The experimental groups attended face-to-face and virtual courses, with online discussions and quizzes, while the control groups only received face-to-face courses. They found that the learning outcomes in the experimental groups were better than those of the control groups and that in this educational scenario, there is a positive correlation between learning outcomes and the level of activities in the virtual environment.

For Baber [21], the migration to virtual education that prompted the Covid-19 pandemic led many researchers to focus their work on the achievement of learning outcomes and student satisfaction. His study aimed to examine the determinants of achieved learning outcomes and their influence on student satisfaction. He found that factors such as classroom interaction, student motivation, course structure, teacher knowledge, and teaching model positively influence learning outcomes and student satisfaction.

Yusnilita's study [22] illustrates the impact of virtual education on the achievement of learning outcomes. She used a descriptive qualitative study method and found that for 65% of students' virtual classes are easier than face-to-face classes; that 85% prepare their learning by taking notes or through recordings, and that for 90% virtual education is more practical. On the other hand, 75% of students feel more confident in virtual education than in traditional education, and 60% think that virtual education improves the quality of their learning. The author concludes that virtual education provides students with practical and flexible learning while making them more creative and active, so their learning outcomes are more satisfactory.

2.2 Interactions in Virtual Education

Danesh et al. [23] examined the role of technology in interaction and communication in virtual education. The results showed that student-teacher and student-student interactions, synchronous or asynchronous, are perceived as effective modes and play an important role in achieving learning outcomes. Students are more engaged in virtual education than in face-to-face education. On the other hand, Moore et al. [24] research sought to determine the acceptability or otherwise of student-to-student interaction in virtual education. They surveyed more than 200 graduate students and, while some desire this type of interaction, most do not like or do not want to participate in it.

Alhih et al. [25] assert that interaction plays a basic role in fostering usability and quality in virtual education and is one of the standards used to reveal evidence of practice in this environment. Their study aimed to assess the levels of interaction in virtual education practices. In the interaction and satisfaction survey, they used the collected information about student-student, teacher-student, student-content, student-interface, and student satisfaction interaction. The results revealed that there is a greater need to raise awareness among all actors involved in virtual education about the importance of interactions in this environment.

While researchers agree that student engagement is key to achieving learning outcomes, it appears that the issue of interaction in virtual education is still unresolved [26]. This author investigated student interaction and engagement in virtual education and compared what he found with the level of achievement of learning outcomes. He found significant relationships between students' success and their participation in virtual courses, but not with interaction. The conclusion is that they can have a satisfactory and meaningful learning experience, despite not having student-student interaction.

Following the principle of educational psychology, a collaborative learning approach incorporates online learning activities to foster active interaction and cultivate problem-solving skills through student discussion, Hussin et al. [27] conducted a study to identify the classification of interaction between students in virtual education. The results of this study contribute to the existing literature on the types of interactions that occur in virtual education and propose strategies to improve them.

The qualitative study by Yeboah et al. [28] analyzed the interaction between technologies used in virtual education and the level of achievement of learning outcomes in culturally diverse students in different academic programs. They found that technologies facilitate educational experiences and the achievement of learning outcomes, which supports the need for teachers to incorporate them into their teaching model.

For Gulton [29] virtual education, which came about due to the Covid-19 pandemic, changed the learning environment of traditional education, so he oriented his research to analyze the role of teacher-student interactions in the achievement of learning outcomes. For this author, the skills and abilities of the teacher are variable and cannot be separated from the level of achievement of learning outcomes in an educational environment dominated by technology. The teaching model that the teacher uses in virtual education must adapt to the conditions of the system and influence how learning outcomes are achieved. In addition, their ability to interact with students through technology is a key factor in assessing learning outcomes and the quality of education.

The objective of the research by Alawamleh et al. [30] was to explore whether virtual education hurts teacher-student interaction and whether it affects learning outcomes, to evaluate and suggest ways to improve such interaction. The results reveal that students still prefer traditional education due to the problems they face in virtual education: lack of motivation, low understanding of the material, decreased levels of interaction with teachers, and feelings of isolation. The conclusion is that teachers should improve interaction with students, and use informal channels in parallel with formal ones. Likewise, teachers should encourage students to participate and study by using different incentives and improving the teaching model.

3. METHOD

The research review on the impact of virtual education teaching activities on learning outcomes shows that interactions are important for improving learning achievement. However, few studies have found that identify the degree to which they impact learning outcomes. Furthermore, on issues such as determining impact factors, design guidelines, and how to implement these activities to improve the achievement of learning outcomes, there is also little research.

In this study, to determine the impact of interactive activities on learning outcomes, the following interaction types were chosen: teacher-student, student-student, student-content, and student-technology and each interaction pattern was modeled through one or more parameters. We did not use data from student surveys, but rather an analysis approach to learning outcomes with data collected from student interactions in virtual education learning activities, which were taken from the database of the system used. Based on these data, the degree of correlation between the variables of the factors is determined and a regression model is constructed with those that have a direct relationship to the achievement of the learning outcomes.

The sample consisted of 54 undergraduate students attending a Computer Science course in three different groups. In the classes, working groups of 5 students were formed to carry out group activities. The course has a duration of 16 weeks which students attend virtually twice a week, and receive advice on activities under their teaching model, to be applied in the virtual laboratories. Several interactive learning activities were designed for each of the selected types of interaction.

3.1 Activities with teacher-student interaction

The teachers organized a teaching model that could be used in both virtual and face-to-face education, in which they incorporated the BigBlueButton tool into Moodle to work virtually. Activities with teacher-student interaction focused on answering questions on topics related to the development of class projects and independent work consultations. Students used the hand-raise function to participate in discussions, and in the labs, the teacher guided them in the use of languages and tools for the development of web applications.

Due to the number of questions that students ask, the teacher is not able to answer them all, so many do not receive feedback on their doubts; in addition, many are formulated confusingly, so the teacher must select the clearest ones to answer them. Faced with this situation, the teachers had to develop a tool for students to formulate questions while participating in the teaching activities.

This tool facilitates teacher-student interaction because everyone can participate and send the necessary comments. The list of questions and comments is displayed to the whole group and students can select the ones they find most interesting or have the most relevance to the class. Therefore, the teacher does not need to respond to all the questions and comments, since the students themselves select the ones that most catch their attention.

3.2 Activities with student-student interaction

Students are in charge of implementing the activities for interaction among them: group exercises, wiki documents, peer evaluation, and forums. The teacher presents the projects and the requirements of the group work so that the student teams select the topic they like the most for the course, with the obligation that each group must develop at least three group activities during the course.

In addition, each team selects a project to develop during the course, which is evaluated in three phases: 1) the students of each team individually evaluate themselves according to the contribution they made to the development of the project, with grades between 1 and 5; 2) based on the individual grade, the other members of the team discuss it and can decide to leave it the same, decrease it or increase it by consensus; 3) the teacher evaluates the results of the practical activities taking into account the achievement of the objectives within each project.

Each team writes a wiki study document about the specific content of the project, which will be evaluated by the teacher and the other teams. For this, they use the Moodle workshop tool through participatory sessions, in which all members participate until the end of the course. In the laboratory activities, the teams write another document about the process used to develop the selected web application. In addition, the course has a forum in which the students exchange opinions and results of the activities they are carrying out, as well as the necessary information for the teacher or the other students about the course topics.

The level of participation of each student in this forum is a criterion to be taken into account to evaluate their attendance and contributions.

The course grade for each student is calculated by weighting the evaluation to the achievement of the learning outcomes: 1) in the development of individual and group activities, tests, and exams, and 2) through their attendance and contributions to the learning activities. The weighting is based on two principles: 1) a final exam with a weight of 50%, and 2) the grade assigned by the professor after analyzing the periodic individual and group evaluations and the interaction in the wiki and the forum, with a weight of 50%.

3.3 Implementation

Students must take a final exam and actively participate and interact in the learning activities designed weekly: 1) consult the material that the professor updates periodically, 2) contribute to the forum discussions, 3) perform the proposed individual exercises, 4) participate in the team that develops each project, 5) contribute to the construction of the documents in the wiki, 6) develop the tests in Moodle, 7) join the virtual classes via videoconference, and 8) ask questions and participate in the classes.

The necessary data are collected from the system database reports and the attributes are adopted from the study to the teacher-student, student-student, student-content, and student-technology interaction activities, which are measured for each view or publication made by the students in the system.

To assess the relationship between interactions and learning outcomes, the correlation between the total number of interactive activities and their impact on the achievement of learning outcomes is examined.

3.4 Limitations of the Research Approach

1. In terms of structuring, the learning activities use the available tools of the system, so the diversity of interactions depends on their support. Since it is possible to access other tools to collect and analyze the interaction between the learner and the system, some parameters were selected to determine the interactions between the learning activities based on the implemented types.

2. Regarding the internal limitations to validity, the data collected for analysis depend on the learning activities implemented in the course, therefore, the level of impact of interactions on learning outcomes depends mostly on the teaching model. The point is that, if there are full ranges of learning activities, it will be relatively easy to identify the factors that affect learning outcomes and vice versa, but if the teacher implements limited learning activities, this identification is complicated.

3. The external limitations to validity are that to accurately analyze the impact of interactive activities on learning outcomes, restrictions and requirements for student participation are required. Then, if the time of participation in activities is not adequately long, there will not be enough data to analyze the correlation between the interaction of activities and learning outcomes.

4. In general, to have sufficient information to determine the impact of learning activities on the achievement of learning outcomes, there must be a synchronous implementation of the course structure, the teacher must implement an adequate teaching model, and the students must participate regularly in the course. Without adequate consistency between these factors, the determination of the impact of virtual education learning activities on learning outcomes will not be efficient.

4. RESULTS

4.1 Correlation between interactive activities and learning outcomes

The correlation matrix in Table 1 shows that the variables correlate with the achievement of learning outcomes. The factor variables used are: 1) teacher-student interaction, through the use of materials PEM and assigned activities PEA; 2) student-content interaction, through the retrieval of material ECM and assigned activities ECA, and other interactive activities such as wiki, workshops, forum, and quizzes.

Table 1. The correlation coefficient between learning activities and learning outcomes

	RA1	PEM	ECM	PEA	ECA	Wiki	Workshops	Forum	Tests
RA1	1	0.163	0.176	-0.031	0.014	0.085	0.285*	0.105	-0.159
PEM		1	0.604**	0.099	0.212	0.273*	0.080	0.276*	0.029
ECM			1	0.230	0.154	0.215	0.099	0.157	-0.138
PEA				1	0.171	0.097	0.155	-0,052	-0.111
ECA					1	0.137	0.049	0.166	0.111
Wiki						1	0.216	0.328**	0.005
Workshops							1	0.213	-0.121
Forum								1	0.234

*The correlation is significant at the 0.05 level. **The correlation is significant at the 0.01 level

The correlation coefficient that had the greatest impact on learning outcomes is student-student interaction through workshops as a learning activity ($r = 2.85$, $p < 0.05$). A close correlation is also found in other interactive activities, for example, student-student through wikis and forums ($r = 0.32$, $p < 0.01$). Related explanatory variables are included in the model to consider the impact of interactions on learning outcomes.

4.2 Regression model

To construct the regression model for predicting learning outcomes based on student interactions through learning activities, the correlation matrix of each factor with learning outcomes is examined, and then the most suitable model is selected based on the factors considered. Since the correlation coefficient between student-content interaction through assigned activities and learning outcomes has the lowest value ($r = 0.014$; $p = 0.05$), it is decided to eliminate it from the regression model.

4.3 Correlation between teacher-student interaction and learning outcomes

Table 2 shows the results of the correlation between teacher-student interaction through materials (PEM) and learning outcomes (RA1). The value of R^2 in the cubic model ($R^2 = 0.33$) and the logarithmic model ($R^2 = 0.33$) offer the greatest ability to analyze the two most efficient models for the relationship between PEM and RA1. In this research, a logarithmic-linear model is selected for these relationships.

Table 2. Summary of the model and parameter estimation for PEM (dependent variable: RA1; independent variable: PEM)

Model	Summary of the model					Estimated parameters			
	R^2	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	0.025	1.658	1	66	0.202	6.369	0.073		
Logarithmic	0.033	2.248	1	66	0.139	6.124	0.444		
Quadratic	0.025	0.826	2	65	0.442	6.310	0.095	-0.001	
Cubic	0.033	0.735	3	64	0.535	5.804	0.394	-0.042	0.001
Power	0.035	2.424	1	66	0.124	5.661	0.088		
Exponential	0.028	1.887	1	66	0.174	5.928	0.015		

Also, based on the teacher-student interaction analysis model, Table 3 shows the correlation between assigned activities (PEA) and learning outcomes (RA1). To explain the relationship between PEA and RA1 ($R^2 = 0.08$) the cubic model is selected.

Table 3. Summary of the model and parameter estimation for PEM (dependent variable: RA1; independent variable: PEM)

Model	Summary of the model					Estimated parameters			
	R^2	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	0.002	0.156	1	66	0.694	7.020	-0.042		
Logarithmic	0.001	0.042	1	66	0.839	6.587	0.115		
Quadratic	0.009	0.283	2	65	0.754	6.160	0.261	-0.024	
Cubic	0.080	1.846	3	64	0.148	1.419	3.025	-0.497	0.024
Power	0.004	0.258	1	66	0.613	5.883	0.054		
Exponential	0.000	0.023	1	66	0.880	6.560	-0.003		

4.4 Correlation between learner-content interaction and learning outcomes

Table 4 shows the results of the correlation between student-content interaction through the activity use of materials (ECM) and learning outcomes (RA1). The value of R^2 in the quadratic model ($R^2 = 0.068$) and the cubic model ($R^2 = 0.082$) have the highest value to explain the strongest models for the relationship between ECM and RA1. The quadratic model is selected to analyze the relationship between ECM and RA1.

Table 4. Summary of the model and parameter estimation for ECM (dependent variable: RA1; independent variable: ECM)

Model	Summary of the model					Estimated parameters			
	R^2	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	0.015	1.026	1	66	0.315	6.483	0.103		
Logarithmic	0.045	3.089	1	66	0.083	6.337	0.552		
Quadratic	0.068	2.371	2	65	0.101	5.790	0.555	-0.046	
Cubic	0.082	1.910	3	64	0.137	5.090	1.263	-0.203	0.008
Power	0.057	3.953	1	66	0.051	5.860	0.118		
Exponential	0.024	1.637	1	66	0.205	6.001	0.025		

4.5 Correlation between student-student interaction and learning outcomes

Tables 5, 6, and 7 show the correlation between student-student interaction with learning outcomes (RA1) through the wiki activity (wiki), the workshop activity (workshop), and the forum activity (forum). The linear model is selected to explain the relationship between the workshop activity (R^2 = 0.079) and forum (R^2 = 0.011) with the results of the study. To explain and select the relationship between the wiki activity (R^2 = 0.054), the log-linear model was selected.

Table 5. Summary of the model and parameter estimation for the wiki (dependent variable: RA1; independent variable: wiki)

Model	Summary of the model					Estimated parameters			
	R^2	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	0.007	0.441	1	66	0.509	6.679	0.012		
Logarithmic	0.054	3.797	1	66	0.056	6.215	0.379		
Quadratic	0.016	0.514	2	65	0.600	6.530	0.042	0.000	
Cubic	0.125	3.051	3	64	0.035	5.876	0.262	-0.011	90.387E-005
Power	0.067	4.776	1	66	0.032	5.715	0.081		
Exponential	0.012	0.769	1	66	0.384	6.283	0.003		

Table 6. Summary of the model and parameter estimation for workshops (dependent variable: RA1; independent variable: workshops)

Model	Summary of the model					Estimated parameters			
	R^2	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	0.079	5.690	1	66	0.020	5.888	0.057		
Logarithmic	0.070	4.943	1	66	0.030	5.305	0.590		
Quadratic	0.081	2.871	2	65	0.064	6.053	0.028	0.001	
Cubic	0.081	1.887	3	64	0.141	6.005	0.043	0.000	10.739E-005
Power	0.077	5.519	1	66	0.022	4.792	0.119		
Exponential	0.081	5.787	1	66	0.019	5.428	0.011		

Table 7. Summary of the model and parameter estimation for the forum (dependent variable: RA1; independent variable: forum)

Model	Summary of the model					Estimated parameters			
	R^2	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	0.011	0.741	1	66	0.392	6.637	0.004		
Logarithmic	0.001	0.055	1	66	0.815	6.685	0.035		
Quadratic	0.011	0.365	2	65	0.696	6.639	0.003	80.584E-007	
Cubic	0.015	0.316	3	64	0.814	6.542	0.014	0.000	40.239E-007
Power	0.001	0.044	1	66	0.834	6.341	0.006		
Exponential	0.011	0.724	1	66	0.398	6.274	0.001		

4.6 Model to predict learning outcomes related to interactive activities

The possible explanations of the variables for the results of this study were included in a multiple regression model: logarithmic (PEM), quadratic (ECM), cubic (PEA), logarithmic (Wiki), workshops, and forum. The Sig. value in Table 8 provides information that gives confidence to the regression model, moreover, the variables can explain the learning outcomes. With the results in Table 8, the general model can be used to predict the learning outcomes: RA1 = 5.291 þ 0848 * logarithmic (PEM) þ 0711 * logarithmic (wiki) þ 0049 * workshops - 0.001 * cubic (PEA) - 0.002 * forum - 0.004 * quadratic (ECM).

Table 8. Coefficients of the variables in the regression model between RA1 and factors (dependent variable: RA1)

Model	Unstandardized coefficients		Standardized coefficient	t	Sig.	Collinearity statistics	
	B	Std. error	Beta			Tolerance	VIF
(Constant)	5.291	0.632		8,378	0,000		
Logarithmic PEM	0.848	0.778	0.151	1.091	0.280	0.741	1.349
Quadratic ECM	-0.004	0.012	-0.048	-0.320	0.750	0.629	1.590
Cubic EAP	-0.001	0.001	-0.095	-0.700	0.487	0.759	1.317
Logarithmic wiki	0.711	0.494	0.190	1.439	0.155	0.809	1.236
Forum	-0.002	0.004	-0.059	-0.444	0.658	0.800	1.249
Workshops	0.049	0.025	0.241	1.926	0.059	0.903	1.107

4.7 Correlation between interactive group activities and group learning outcomes

Table 9 shows the results of the correlation between group interactive activities, which do not reflect the interaction between group activities and group learning outcomes because the value of R^2 is very small ($R^2 = 0.04$).

Table 9. Variable interaction coefficients and group learning outcomes (dependent variable: R^2)

Model	Unstandardized coefficients		Standardized coefficient	t	Sig.	Collinearity statistics	
	B	Std. error	Beta			Tolerance	VIF
(Constant)	8.362	0.786		10.646	0.000		
Interaction	-0.003	0.003	-0.211	-0.747	0.469	1.000	1.000

5. DISCUSSION

This research evaluated the impact of different types of virtual education interaction on the achievement of student learning outcomes. To determine this impact, the quantitative results identified the interactive activities that had the greatest influence on students' academic performance. The statistical results indicate that this impact can be classified from the forms of student-student, teacher-student, and student-content interaction, among which the influence of student-student interaction activities presented the greatest impact on the achievement of learning outcomes (0.71) in the linear regression model. It should be taken into account that the achievement of learning outcomes in a virtual education environment depends on several factors, so the activities analyzed in this research may represent only a minor percentage.

When the regression model of the variables is not linear, the teacher-student interaction impacts to a lesser extent the achievement of learning outcomes, which may be due to the frequent changes in the form and sequentiality of this interaction in virtual education, which poses a challenge for the teacher when designing the teaching model, but also for the system environment and the tools on which the interaction takes place.

The student-content interaction in the regression model has a low impact on the achievement of learning outcomes, a result consistent with those found in similar studies, which found that the impact of the student-content interaction was lower than the other types of interaction. Other studies found that this interaction had the greatest impact on the achievement of learning outcomes, which can be explained by the learning activities implemented, which were designed and constructed differently, and also because the type and frequency are also different.

On the other hand, it was determined that group interactions do not have a greater impact on the achievement of learning outcomes by individual students, or on group learning outcomes. This result supports the findings of other research analyzed in the literature review.

The findings of this research pose a challenge for teachers in terms of how to structure the teaching model and for the design and implementation of learning activities for virtual education. In this study, learning activities were designed and implemented consistent with the most used types of interactions in education: teacher-student, student-content, and student-student, in addition to others such as wiki, forums, and workshops, but it is concluded that, if the course does not have the latter, then the results will be different.

According to the results, student-student interaction has the greatest impact on the achievement of learning outcomes. This can be used to improve the teaching model and to design and implement learning activities supported by more interactive styles. This finding and suggestion are similar to what other studies have found, which indicate that student-student interaction has the greatest impact on the achievement of learning outcomes, while teacher-student and student-content interactions have a lower impact.

The results of this study demonstrate that traditional education, in which the teaching model is teacher-centered, is not the way to educate people and train professionals in this century, since the role of the teacher should be as a guide-advisor, rather than an oracle of knowledge. Furthermore, if the objective is for students to better achieve the learning outcomes, then different types of assessment should be designed and, for students to maintain a high degree of concentration, the teaching model should include sufficient formative assessment events.

6. CONCLUSIONS

In virtual education, many factors impact students' achievement of learning outcomes, and finding the specific factors and analyzing the extent of their impact are complicated issues to investigate. In any case, this study examines and analyzes how interactive types and factors impact the achievement of learning outcomes, for which an investigation was carried out by designing a series of learning activities that sought to reflect the interactions between the actors in the educational act: teacher-student, student-content, student-student, and student-technology.

The results demonstrate the affirmation that the teaching model and interactions have an impact on the achievement of learning outcomes by students and that among them the one with the greatest impact is the student-student interaction. This is consistent with the results presented by most of the works analyzed in the literature review.

The limitations of the research approach in this study pose major challenges for related research: can or cannot a teaching model be designed and implemented to predict students' academic performance in virtual education? Does using a wide variety of interactive activities in a virtual course help students to better achieve learning outcomes? Does applying a diversified and continuous assessment model serve as a tool to improve the achievement of learning outcomes?

In any case, and although the results of this study can be considered limited, the research serves as a basis for teachers to initiate processes aimed at improving their teaching model and design a better-structured evaluation model.

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XIX
Issues and challenges in professional teacher training for the New Era

As societies progress and humanity enters the New Era, an educational paradigm emerges in which the classroom is expected to cease to be a place where students come to watch teachers work. What the new century, the New Era, the New World Order, and the new category of students demand is that schools become learning centers, where students are participatory actors, where what they know is valued, and where they are assessed through the achievement of learning outcomes through a teaching model focused on their needs and expectations. In this teaching-learning environment, the dynamism of student-teacher relationships stands out, which is why an innovative approach is required to manage the classroom and the institution. This chapter describes the need for an educational revolution in the professional training of teachers because the world today needs a different type of teacher for different types of students.

1. INTRODUCTION

The New Era, which humanity has entered in the last decade, demonstrated the need for a revolution in the educational system and innovation about the assumptions inherited from the nineteenth century that are still part of it. Some of the principles on which this paradigm is based are: students sit passively in rows, the teacher is the one who knows, students are the ones who learn, the teacher must complete a compulsory curriculum and students must develop competencies. Likewise, the admission system classifies students by year of birth, and the evaluation system reinforces a status quo in which only some learn.

Although the New World Order requires all people to be educationally successful, the education system enforces a learning curve in which only a few learn. This serial schooling classifies students according to socio-economic and cultural strata and differences, highlighting the inability of many teachers to adapt their teaching model to the learning model, needs, and expectations of individual students. Currently, many people around the world are disengaged from the traditional education system [1-3], a situation that reflects the failure of the education system.

This loss of talent affects the development of nations for the New Era, in which critical thinking, problem-solving, adaptive reasoning, teamwork, transdisciplinary research, and innovation capacity are essential skills. All this originates from a teaching-learning model in which leadership is more a function of management than of transformation, where faculties of education still train their students to work in traditionalist institutions, and not for those needed by humanity for the New World Order [4].

In the New Era, the school ceases to be an institution where students go to watch teachers work and becomes a learning center for their active participation, where their learning model is valued and the teacher innovates the teaching model according to the needs and expectations of the students. The development of new technologies facilitates this innovation because it is not only about teaching content but also about pushing the boundaries of exploration and mastery of ideas and knowledge [5]. In this model, the center of teaching-learning is the students and the institution and teachers must structure curricula adapted and suitable for them, not based on obsolete regulations. Furthermore, in this innovation, the evaluation system revolves around learning outcomes, through technology-based didactics, thus achieving the real objective of training people and training professionals [6].

Likewise, the educational environment of this century demands different leadership for the school and the classroom, because the New Era is complex and dynamic, it empowers teachers to take on new challenges and to drive education based on learning outcomes, not competencies. That is why they need to train professionally and develop new and revolutionary skills because students need to be trained and empowered for success so that they adapt to the changing culture and expectations of society.

In the nineteenth-century education system, leadership was assumed by the curriculum and the derived contents, teachers were the center of the educational model, evaluation was passive, and students were only passive learners who had to attend school because they did not know. In the New World Order students are active, protagonists, and passionate, then, the system has to focus its model on them and their commitment to humanity, so it needs to recognize them as subjects who know, who learn individually and differently, and who need to be evaluated through high-level learning outcomes.

This implies that teachers must be trained in innovative universities because the changes that are generated are profound for the success of their performance. In the education system, the belief persists that teachers must be trained based on an obsolete pedagogy, in which the preservation of teaching around curricula and the passive regurgitation of information prevails. It is a pedagogy that places students in schools as they are, not as they should be for the New Era. The current educational system is only reproducing and perpetuating the obsolescence of 19th-century education.

This chapter describes the need for a revolution in this system, a conceptual justification to meet the needs and expectations of the new category of students, and for the social, technological, and professional changes of the New Era. It is argued that teachers must be educated and trained through programs that overcome the rusty principles of traditional education. It is argued that universities must structure professional training programs for innovative teachers to meet the challenges they face in the new school.

2. OLD PROBLEMS, NEW PROBLEMS

The professional training of teachers varies around the world depending on the region, nature and focus of the curriculum, quality of the trainers, institutional assessment of the program, and the trade-off between theory and practice, among others. Faculties of education are classified as excellent, good, or poor; some are innovative, some are traditionalist, some remain anchored in the so-called old school, and others are simply poorly managed. Although in some countries criticism of teacher training is censored and no assessment is allowed, it is worrisome that many governments dismiss teacher professional training, and enact policies and regulations that hinder its development. Meanwhile, teacher professional training is not adequate for the needs of the New Era [7, 8].

This statement is supported, to a greater or lesser extent, in all countries, where teacher training travels bumpy roads, responding to the whims of the government of the day and not to State policies, with low salaries and lack of recognition, and where professionals from other areas find in this profession a refuge when they cannot get a job [9, 10]. In addition, it is accepted as a paradigm that teachers entering education come from adequate university training, that they are reflective professionals capable of structuring adequate teaching models, and that they serve as learning scientists from the first day in the classroom.

This situation dates back to a time when society evolved in a way that was contradictory to the hope of where education was expected to take it, and where expectations in teacher training reflected the contradictions inherent in the development of the world. The development that humanity has reached in this century should be sufficient for nature to intervene adequately and break down the walls of inequity and injustice, but education cannot yet be considered as a support to achieve this. In the twentieth century, humanity experienced overwhelming times, while the education system remained remarkably unchanged from the nineteenth century. Although teacher training has evolved, the same cannot be said of the regulatory requirements for entry into the profession, because most teachers do not come from faculties of education, but other professional areas.

These contradictions are a reflection of an educational culture that is hurried and, like society, trapped by ease and immediacy. The culture of the 21st century is governed by speed: food, news, media, networks, communication, relationships, and training; which generates, among other things, diseases and weakening of the social fabric, making individuals more vulnerable. New technologies and research advances have two sides: on the one hand, they facilitate many human activities and, on the other, they increase the gap between rich and poor countries.

Although many resources are invested in trying to close this gap, especially in education, economic inequality and lack of opportunities are increasing. Part of these resources are invested in increasing the supply of short-term teacher training programs, but without a structured study of the need and with a feeling contrary to the needs of the school, because the profit mentality prevails. Making education a business, where teachers are desired to be as fast and cheap as hamburgers, a kind of microwave teachers who do not teach, do not form, and do not train.

In the last century, the education system developed a grading regime to ensure that only one-third of students would succeed and achieve a degree. It established global regimes in the form of tests (examinations) and used the normal curve and psychometrics as a basis for governments to make decisions.

Among these standardized tests are mentioned: Intelligence Quotient IQ of France, the Scholastic Aptitude Test SAT of the United States, the Australian Tertiary Admissions Ranking ATAR of Australia, the Programme for International Student Assessment PISA, and the Programme for the International Assessment of Adult Competencies PIAAC of Organisation for Economic Co-operation and Development OECD, Trends in International Mathematics and Science Study TIMSS and Progress in International Reading Literacy Study PIRLS of International Association for the Evaluation of Educational Achievement IEA, among many others; in addition to those that are applied regionally or nationally around the world and that rank students and graduates based on predetermined assumptions of knowledge and future success, but especially on their ability to memorize.

It is only the perpetuation of a chain education system based on false assumptions: 1) only one-third of students complete their studies and develop skills and abilities, that they demonstrate on standardized tests and which qualify them to succeed as professionals; 2) one-third of students finish high school and develop reading and writing skills and abilities, which qualify them as skilled laborers; and 3) one-third of students do not survive curriculum-based education and drop out, so they can only aspire to lower-level positions in the capitalist economy [11].

The education system, with teachers as protagonists, must ensure that all people develop their full potential because they deserve the opportunity to lead a life without restrictions. But the way the education system is structured, where one-third of students do not reach a basic level of education, what is achieved is that economic and educational gaps perpetuate social inequality and inequity, which eventually widen and give rise to social unrest.

If we talk about the professional training of teachers being a disaster [12], we must also recognize that families have questions about education: is today's school adequate? Should teachers design teaching models for the achievement of learning outcomes or for passing standardized tests? Should they recognize students and identify their individual needs and expectations or force them into generalized curricula? This disaster may be the reason why in education faculties students receive contradictory messages from their professors, on the one hand, the experienced ones advise them to forget everything they learn at university and prioritize what they learn in the real world and, on the other hand, the less experienced ones recommend them to innovate their models and integrate into schools, universities, and communities, because this way they will recognize what families expect from their children's education.

In this same sense, many reports and studies criticize the professional training of teachers, without serious recommendations on how to improve it, triggering the structuring of new rules, regulations, exams, and responsibilities to follow up on their functions. So, in this century, it is the most regulated profession, but it has not changed on issues such as curricula, content, assessments, and learning outcomes, turning education into an exercise of results through compliance marks [13, 14]. The reality of the New Era and social problems support the need for a revolution in the education system and the way students are trained in faculties of education because the goal is to break down barriers so that all people receive real education and training.

3. SAME PROBLEMS

In the 19th century, it was common for teachers to have a curriculum, a guiding text, a didactic of writing on board, speech as a pedagogical model, rows of seats for students, and an iron discipline for the class, and for students to have to adjust to the teacher and the curriculum, not the other way around [15]. This was an education for the production line, and although some students did well, many dropped out of school and others did not even try. By that time, if people worked hard after school, even if they dropped out, they could still aspire to a job in a factory, mine, or workshop.

Teacher training emerged from the assumptions of training for that chain and in a two-dimensional education: sitting and listening. Since then, students have attended school only to watch teachers work, institutions structure a restricted pedagogical model of teaching-learning [8, 16] and emphasize generalization rather than personalization, a system that is still in place in much of the world.

In the New Era, we must talk about multidimensional education, which teachers must understand to design an innovative, dynamic, collaborative, and global teaching model [17, 18]. While people learn to perform well in that two-dimensional model, those who cannot or do not want to do so find very little room to work, therefore, it is long overdue for the education system to be done with this model [19].

In this multidimensional education, the education system has to innovate the standards for the professional training of teachers, because the teaching-learning model with which they are trained is obsolete for the needs of the New Era. This generates a recurring situation where experiences and research show that, after graduation, they practically do not use what they learned at university [20]. The short-term objective should be to revolutionize the education system and reinvent the professional training of teachers, including the needs, knowledge, and expectations of the new category of students, and involving the developments and discoveries of neuroscience, valuing the important role that teachers play in the formation of people and the training of professionals for the 21st century.

The majority of teacher training programs in the world have few differences, they are regulated using organizers or standards that must be passed to achieve accreditation but are limited to simple indicators with which they are qualified. In this way, there is no need to innovate, because if the indicators do not change, then why change the traditional way of educating and training teachers? Another consequence is that a kind of vertical silos have been created in which universities work in isolation, even in the same countries, but with remarkable similarity and little innovation. A new way of thinking about the professional training of teachers is needed, through horizontal conversations based on the results of educational research around the world.

The new category of students must receive adequate education and training for the demands of the New Era, and for every professional to be successful in his or her profession. The way teachers are educated and trained must be revolutionized and, without abandoning the demands of educational quality, the education system must heed the signals of the New World Order. It is not possible that the so-called informal education is openly calling for people's attention to be trained, while they abandon formal education, because they do not feel included or attended to as they expect. The knowledge bases, institutions, teaching models, and teachers in the informal setting go unnoticed by regulators and standards while tightening the requirements for entry, retention, and exit of teachers into the formal setting of the rusty education system.

4. CHALLENGES IN THE PROFESSIONAL TRAINING OF TEACHERS

The problems of the education system are many and one of them is the quality of the programs with which teachers are trained. Although the literature, research centers, and many other sources describe the challenges facing teachers in the New Era, it is not easy to discover recommendations for faculties of education to train them professionally to be better-practicing teachers. Following, and after analyzing the results of our research, we describe some recommendations to guide the professional training of teachers for the New Era.

4.1 Recognizing students

A challenge for teachers in this era is to recognize the people they meet when they open the classroom door, identify them individually, know the context and environment in which they live, why they are in school, what they want to learn, what they need to learn, what their needs and expectations are, what their cultural background is, whether they have access to technology and what their mastery of it is, among many others. This is a basic activity, which can be carried out using Artificial Intelligence through a program, through observation, or by talking to them. Recognizing them is essential for their success as students in school and family environments.

Since the education system assumes that everyone is equal and has already programmed beforehand what they have to learn, the teacher enters the classroom with a structured curriculum in which he/she has no margin to carry out this activity, because he/she must execute the programming 100%, even if he/she does not know if the students learn. Here it is necessary to revolutionize the education system and activate the actors involved in the process of education and training of students, and the teacher must learn to incorporate the community and the family in their education [4].

4.2 Find out what students know and what their learning model is

Since the beginning of the century, developments and discoveries in neurocognition have been published that can contribute to solving problems in the educational system [21] because they form a new transdisciplinary area of education research. For the traditional school, it is not necessary, because everything is already known about how people learn, but this research shows that we are just beginning to understand learning and its multiple forms and contexts. Most of the knowledge discovered comes from research on the brain [22, 23], cognitive computing [24], artificial intelligence [25], physical activity [26], and other areas.

We must also add the impact of new technologies, which in the classroom are reduced to the meaningless use of computers. Teachers need to discover what students know, what their learning model is, where they learn when they learn, and what motivates them to learn. They must discover that learning is rigorously linked to complex aspects of natural intelligence, such as reasoning, perception, knowledge representation, expression in natural language, abstraction of concepts, and recognition of analogies, among others [8].

4.3 Innovate the curriculum and design challenging learning outcomes

In the education system, schools are mere testing centers, rather than learning environments, while, to succeed in the New Era, students must be trained with an innovative curriculum and develop the skills they need for new jobs. However, it turns out that education is still bounded by 19th-century principles and concepts and remains immobile in the face of the rampant development of other areas of knowledge [8]. This is why students are being prepared to work in jobs that no longer exist when they need to be trained to fill the jobs that are emerging.

Today's curriculum and learning outcomes need to be geared towards developing skills, abilities, and capabilities such as reading and writing for effective communication, abstract and systems thinking to understand and solve complex problems, adapting to automated environments, and working with and for machines, among others for the New Era. Students must find passion in studying, and develop critical thinking and creativity while fostering their curiosity for innovation. That is why teachers must go beyond the curriculum structure an innovative teaching model, and structure and adapt learning outcomes to future needs, not the needs of the moment because students will be working in an unknown environment today.

4.4 Knowing the New Era and the New World Order

Since the beginning of the 21st century, new technologies and social media platforms have been driving the reorganization of how value is produced and created in companies, and how knowledge is created, disseminated, and used. These are structures that go beyond the basic forms and processes with which society was familiar, opening up a range of possibilities for those who are capable. This New Era forces the education system to rethink the skills to be developed by students and teachers, who must innovate and develop new ways to achieve them.

In this way, we will be able to form and train people with global thinking and skills, conscious, curious in learning about the New World Order and how it works, to intervene responsibly; capable of generating great ideas, tools, and transdisciplinary methods to respond to any situation. An education that implies rethinking current practices and recognizing that, unlike what is still believed, there are no simple recipes to achieve it. That is why teachers must experiment with ideas, challenge concepts, and share results with the community.

4.5 Recognize themselves as counselors

Knowing what and who they are, where they are, what they do, what their responsibilities are, and how to behave as learning leaders is the responsibility of all teachers. They are no longer the first and last voice in the classroom, the one who possesses the knowledge, the only one who evaluates, the solitary authority; now they must position and recognize themselves as an actor who accompanies, advise, attend, and is flexible, who listens, who respects, who defends and supports the student while remaining a leader who communicates with families, employers, and society. He must give value to revolutionary and innovative knowledge and to content that generates questions, and apply a teaching model for students to achieve learning outcomes. There can be no imbalance because the teacher is a social being, an advisor, a leader, and a reference for all the actors in the teaching-learning process in the New Era.

In the New World Order, it is expected to assume the role of the advisor of a process-oriented to educate people and train professionals to successfully meet the social demands, so it needs to keep updated in knowledge and on the realities that students will have to face. That is why a new type of teacher training is required, professionally trained and with updated knowledge. In short, it is a different type of teacher, professionally trained for a different type of school and students.

5. CONCLUSIONS

Among the most pressing problems facing the education system are the professional training of teachers and curriculum innovation. For continuists, attached to the traditions of the 19th century, this may seem like heresy, but the education system must be revolutionized and accept that the curriculum, content, teaching models, and didactics must be structured based on the knowledge, needs, and expectations of students in the New Era. It is necessary to overcome continuism because it has already been demonstrated that it is not adequate today, and accept that the passions, knowledge, and learning model of students is what helps them to drive their curiosity and keeps them interested in education.

The goal of the teaching-learning process is to design schools based on and structured around the needs of students, not around curricula and the whims of the education system. Thinking and acting in this way differentiates innovative and restless teachers from continuists and conformists because they keep up to date with technological advances, intelligent tools, and discoveries in neuroscience. This is a path that education faculties must begin to travel to train teachers professionally so that they are trained to make the transition between a traditional education system and a revolutionized one.

Academia, industry, and governments need to move education forward at the same pace and in the same direction as other areas of knowledge because the psychological, cognitive, and emotional ramifications of digital engagement of the new category of learners are unique but almost unknown. Moreover, the same findings in brain research and neurocognition reaffirm that they are neurologically different because they have developed a kind of cultural brain that reconfigures their mind.

The education system must train and professionally train teachers, with global thinking and skills, conscious, curious in learning and teaching about the New Era and the New World Order; to develop learning outcomes that empower students to intervene responsibly, able to generate and use great ideas, tools and transdisciplinary methods to respond to any situation and to engage in a changing world; an education that involves rethinking current practices and recognizing that the student is at the center of the process. That is why teachers need to experiment with ideas, challenge concepts and share the results and visions with the community.

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XX
Social perception of engineering education: A descriptive study

This chapter presents an analysis of the social perception of engineering education for the 21st century from the point of view of students, professors, practicing professionals, and businessmen, about relevant aspects and components of engineering education and training. A virtual survey was applied in Australia and Colombia to these actors, active in different moments of their career and profession, as well as to industries in different engineering areas. For the students, it is very important that the curriculum includes practice in real engineering contexts; the professors consider it very important that the students develop teamwork and communication skills; the practicing professionals affirm that the ability to integrate into the productive environment and to use new technologies is essential for success in engineering; while the businessmen give greater value to engineers being proactive, innovative and team players.

1. INTRODUCTION

The general acceptance, both in the business context and in the family and social context, is that the quality and nature of a person's education and training have a positive effect on the effectiveness and efficiency of his or her professional practice, and this could not be truer than in the area of engineering. It cannot be forgotten that this discipline is the basis for the development and progress of countries and that if the educational system and higher education institutions do not educate and train students in such a way that they are adequately prepared to successfully develop complex projects they will encounter as professionals, then it will be the company (if it is willing) who will have to assume this role, which, in most cases, is usually a costly and time-consuming process.

The issue is that the industry does not have in its budget the function, nor is it part of its business model, to offer general training to new employees, because it should be the educational institution that is responsible, by its nature, to do it with dedication and seriousness. It cannot be expected that students, only through outdated theory and paper practices far from the real industrial context, will be prepared to join the workforce that will allow the country to improve its progress and development in the New Era. That is why it is expected that the education system, institutions, teachers, and students have the scenarios, knowledge, and practices for engineering professionals to be competitive because they have developed skills, capabilities, and abilities to integrate smoothly into the labor market.

While it is true that universities cannot offer all the knowledge and practice those professionals need, it is also true that this century is the right time to make the university-business-state conjunction a reality, because up to now, and in most countries, it has been nothing more than a mere slogan without any effective reality. It is the responsibility of the academy to keep the curriculum up to date, to hire professors with real business experience, and to structure practices based on real life. For its part, the company should include in its business model a section to work with the academy and serve as an advisor and consultant for the academy to innovate the engineering curriculum, because it is through this alliance that students can learn how the activities in which they will perform as professionals are developed. While it is the responsibility of the State to formulate policies adjusted to the realities of the New World Order regarding the quality of education, most importantly, to follow up on them; because a well-written standard is useless if there is no real process of implementation, monitoring, and follow-up.

This research analyzes the perceptions of students, professors, professionals, and entrepreneurs from different engineering areas about the qualities and capabilities that an engineering professional must develop to be successful in the New Era. A survey was applied to these actors in the engineering education and training process, with open and closed questions in which they were asked about the perceived importance of a series of engineering skills, capabilities, and abilities. Although the study was conducted in 2021, when the world was still amid the pandemic caused by Covid-19, the aim was not to limit the assessments to issues such as educational models or quality of education, because the objective was limited to knowing the assessments in a broad sense. Therefore, issues parallel to the education of engineers were not taken into account.

2. FRAME OF REFERENCE

Several types of research have been developed to analyze the experiences and collaborations that seek to help improve the education and training of engineering students to perform in the New Era, and from their results, it is possible to understand the differences in the teaching and practice processes of the discipline, as well as the techniques and knowledge of the teachers in charge of bringing them to the classroom.

For Grubor [1], Work Integrated Learning WIL offers several benefits, such as helping to prepare students for the workforce. According to the author, institutions must introduce changes to the curriculum to improve the employability of students and decrease the gap between the skills developed and those required by industry. Therefore, it is necessary to implement simplified processes and a greater awareness of these needs among students and professors. In any case, there is great potential in WIL, as it helps to diversify the teaching model, structure flexible options to train students, and involve industry in the engineering education processes.

As part of a larger project, which seeks to determine best practices for establishing and maintaining effective and sustainable collaborative relationships between professionals in academia and industry, Lucietto et al. [2] conducted a review outlining the available materials and the many gaps that exist regarding course content, teaching methods, and practical experience related to preparation in engineering careers. The authors conclude that there is currently no clear agreement on the principles and practices that enable mutually beneficial partnerships between industry, academia, and the state. They also informally state that faculty are often challenged by this lack of research on sound recommendations regarding collaborative efforts.

For Ulrichsen [3] the relationship between the state, universities, and industry has never received as much attention as now. Countries around the world, especially the United Kingdom, the United States, and Europe, are facing the question of how to harness the knowledge generated and developed in engineering and employ it for the good of the economy and humanity, through technology transfer and collaboration with business. Many large companies and universities are struggling to find more effective and productive ways to collaborate, reflecting the many challenges to be overcome in managing partnerships to create and capture value, and the changing global and competitive landscape in which they operate.

According to Marijana and Gotlieba [4], contextual research collaborations between the software engineering industry and academia can provide significant benefits to both parties, including improving innovation capability for industry and the real-world environment, to motivate and validate research ideas. However, building scalable and effective research collaborations in engineering is known to be challenging. While such challenges can be varied and many, the authors focus on the challenges of achieving participatory knowledge creation supported by active dialogue between industry and academia and continued engagement in joint problem-solving.

In many countries there is a growing interest in implementing engineering education as part of secondary education and, to find out what students at this level think about engineering, Kőycű and de Vries [5] conducted a study in 39 countries about their attitude towards and concept of engineering. They conducted a factor analysis to reveal the dimensions of students' attitudes and concepts and found that, in contrast to studies conducted in primary education, high school students have a fairly clear concept of engineering. This predominant attitude toward engineering indicated a rather positive image of engineering.

For Razali et al. [6] the integration of science, technology, engineering, and mathematics STEM benefits the economy, therefore, teachers and academia should pay more attention to the education and training of students, for them to be competitive and meet the needs of the industrial economy. The objective of their research was to determine the direct influence between attitudes toward STEM and the development of interest in STEM careers among high school students. They concluded that fostering an attitude toward STEM provides a new dimension in the learning process for future needs.

Kövesi and Csizmadia [7] found that, in the global knowledge-based economy, the rapid evolution of technology has led to profound changes in the labor market and that, despite the growing demand for highly skilled engineers, companies plan to hire professionals only if they consider them sufficiently qualified and capable of integrating into the organization. Therefore, they require them to have not only a strong technical background but also non-technical skills and capabilities. In the age of digital technology, these new priorities and requirements for engineers' skills are noticeable in the industrial sector. New engineers need to be able to utilize skills such as social intelligence, sense-making, design thinking, convergent and reflective thinking, and virtual collaboration.

In his research, Crosthwaite [8] found that there are strong common themes of desirable components in engineering programs and practitioners, including distinctive program-level philosophies; strong program-level frameworks for industry engagement, including practices for work-integrated learning or input into practice-based courses; systematic use of student-centered active learning, including project-based learning throughout the program, beginning in the first year and incorporating community- and industry-based projects; collaboration with industry and community partner organizations; use of human-centered and empathetic projects; online simulations, quizzes, and role-playing; employment of a range of authentic assessments, including those that assess the deployment of multiple coordinated skills typical of professional practice; and availability of enabling people, processes, systems, and resources, among others. In other words, the future outcomes expected of engineers should be developed by practice-centered programs, addressing real-world complexity, and integrating technical and generic skill development to provide authentic learning.

For most of these authors, and others not included in this study, it must be assumed that teachers' perceptions of engineering are transmitted to students, so it is logical to assume that between practicing professionals and teachers there are very marked differences in the perception of the necessary engineering skills. The point is that if the academy does not adequately train students for professional practice, the industry will have to assume this responsibility, which represents a high investment in money and time, which it is not willing to assume because this responsibility belongs to the educational system and the academy, working hand in hand with the industry and the State.

In these investigations, many differences were found between the perceptions of academia, industry, students, professors, and professionals about what makes an engineer successful. That is why in some of them it is stated that what interests society is that the academy is in charge of ratifying the skills that the engineer should develop, based on listening to professionals in the area and the industry.

3. METHOD

This research analyzes the importance perceived by the social actors of the courses, the curriculum, and the skills and abilities that are socially recognized as basic in the education and training of engineers. A survey was applied to students, professors, practicing professionals, and entrepreneurs related to engineering, in which open and closed questions were used. Among the data, they were asked to report, as appropriate, work experience, the discipline of study, and the degree obtained, among others. They were asked to rate the importance of the curriculum, teaching model, evaluation, content, and literacy skills to become a successful engineer. They were also asked about the importance of mathematics, basic sciences, assertive communication, theory, practice, interpersonal skills, and teamwork, among other concepts, for the professional practice of engineering.

A recurring question for many of the actors in the engineering education process is: *when am I going to use this?* Therefore, with the idea of finding a conceptual reference point, students were asked how often they asked themselves this question about a specific subject. Likewise, professors were asked how often they thought students would use what they had learned in their subjects, and practicing professionals were asked how often they used what they had learned in their careers. Employers were asked to assess their perception of how easy it is to find engineers trained and qualified for the New Era, and how important it is for engineering professionals to have skills for adapting to the production environment, using new technologies, proposing, and innovating, for communication and social integration.

The skills, abilities, and capabilities were chosen arbitrarily and based on the researchers' experience in the engineering field, both at the professional, student, and teaching levels. Consequently, a wide variety of components were included to identify trends and areas for further work.

The sample of participants who responded to the survey was 734, from public and private universities and companies in Colombia and Australia: 492 students (270 Colombians and 222 Australians), 98 professors (38 and 60), 83 professionals (40 and 43), and 61 entrepreneurs (37 and 24). In general, the engineering fields in which students are enrolled are 4% environmental, 3.8% aerospace, 11.5% electrical, 26.5% computer science (informatics, systems, software), 13.1% mechanical, 2.9% civil, 23.3% industrial, and 14.9% electronics. And they are in their first and second year 10.7% (53), third and fourth years 36.3% (178), and last year 53.0% (261). The ages of the practicing professionals range between 20 and 30 years, with work experience between 1 and 10 years in the engineering area. The professors hold Master's or Doctorate degrees in some engineering discipline and have academic experience between 2 and 35 years. The entrepreneurs come from the textile, automotive, mechanical, software, and video game industries.

4. RESULTS

Regarding the participants' perception of the importance of the curriculum, teaching model, assessment, content, and literacy skills in becoming a successful engineer, the results are shown in Table 1.

Table 1. Perception of the importance of components in becoming a successful engineer

Components	Students					Teachers					Professionals					Entrepreneurs				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Syllabus	9	15	28	36	9	2	3	3	9	3	1	1	4	6	0	6	0	2	2	0
Teaching model	11	13	31	35	9	1	4	3	6	4	0	1	7	10	2	7	0	1	4	2
Evaluation	10	15	37	41	10	3	2	4	9	4	0	1	6	9	1	5	1	2	4	2
Contents	8	12	27	37	11	3	1	4	8	2	0	1	6	8	1	6	0	1	3	1
Reading and writing	8	13	28	31	8	4	4	3	7	2	1	1	6	8	2	5	1	3	2	1

(1) Not sure, (2) Not important, (3) Somewhat important, (4) Very important, (5) Essential

First and second-year students have a greater tendency to answer not sure (68.8%), third- and fourth-year students somewhat important (63.5%), and last-year students tend to affirm that the components consulted are very important (71.9%). This difference may be due to the level of clarity they have developed on these issues as they have progressed through their careers. On the other hand, professors with more academic experience tend to think that these components are very important (59.4%) for the professional practice of engineering, and professionals with more years of developing engineering work maintain that they are essential (49%). As for entrepreneurs, there was a tendency to select the option I am not sure about (48.5%), perhaps because they are distant from the academy and do not realize the significance of these components for the success of an engineer. In these ratings, it stands out that Australian employers seem to be more aware of what each component means, so fewer of them selected not sure.

According to these results, the component with the greatest importance for becoming a successful engineer, rated between 3 and 5, is evaluation, followed by the teaching model. It should be clarified here that, in the descriptions of these components, the survey reported that evaluation covered the concept of practice, regardless of the model used to carry it out, so it is feasible that it received a higher rating because engineering is a discipline in which practice is important. Likewise, it is striking that reading and writing, and the curriculum were the least valued in Colombia, that for Australian final-year students the teaching model is very important, and that for Colombians it is the evaluation.

Table 2 shows the perception of those consulted about the importance of mathematics, basic sciences, assertive communication, theory, practice, interpersonal skills, and teamwork for the professional practice of engineering. For these components, descriptions included such as: 1) Mathematics, includes calculus, general mathematics, statistics, geometry, special mathematics, trigonometry, and others that in each country are part of the curriculum; 2) Basic sciences, covers physics, chemistry and biology; 3) Assertive communication, refers to public speaking, language used, public speaking, and speaking another language; 4) Theory, covers the concepts of the content, both in subjects specific to the career and in those called integral and human formation; 5) Practice, is any activity in which the student can validate the concepts and principles of the career; 6) Interpersonal skills, such as listening, dealing with others, culture, knowing how to relate and have fun, and knowing how to place oneself in an administrative structure; and 7) Teamwork, which refers to knowing how to integrate, make valuable contributions, accept suggestions and rejections, integrate transdisciplinary knowledge and have a multidimensional vision of the problem to be solved.

Table 2. Perception of the importance of components for the professional practice of engineering

Components	Students					Teachers					Professionals					Entrepreneurs				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Mathematics																				
Basic sciences																				
Assertive communication																				
Theory																				
Practice																				
Interpersonal skills																				
Teamwork																				

(1) Not sure, (2) Not important, (3) Somewhat important, (4) Very important, (5) Essential

In general, among students, the tendency is that theory (55%) and mathematics (48%) are the least important, with a marked majority among those in their first and second year, but with a tendency to decrease among those in their last year; while practice receives the highest positive valuation (65.3%). Among teachers, mathematics (43.6%), practice (45%), and theory (42.8%) are most highly valued, with a majority tendency among those with less academic experience; but Colombians do not value interpersonal skills well. Among professionals, there is a tendency to give greater importance to assertive communication (54.3%) and practice (61%), and a lower value to basic sciences and theory. For Australian entrepreneurs, interpersonal skills (41.4%), assertive communication (40%), and teamwork (40%) are most important, while Colombians do not place much value on mathematics, theory, and basic sciences.

Table 3 shows the results related to the student's perception of how often they ask themselves, *When am I going to use this?* about the topics of the subjects; of the professors' perception of whether they usually think about whether the students will use what they have learned in their courses; and of the practicing professionals concerning how often they use what they have learned in the course.

Table 3. Perception of questions related to class topics and their utilization

Questions	Students			Teachers			Professionals		
	1	2	3	1	2	3	1	2	3
When I'm going to use this	353	100	39						
Students will use what they have learned				19	37	42			
I use what I have learned in my career							25	38	20

(1) Frequently, (2) Infrequently, (3) Never

First and second-year students ask themselves little (63%) about when I am going to use this, but third- and fourth-year students (57.8%) and senior Australians (68.9%) do so much more frequently, so it could be thought that they are becoming more aware of the course as they progress in their studies. For their part, the professors in both countries who most frequently ask themselves whether students will use what they have learned in their courses are those with more academic experience (42.1%), while younger Colombians do not tend to think much about this (28%), which shows that the experience of the professors is an important factor in the education and training of engineering students. For their part, Colombian professionals tend to use little (51%) or never (40.8%) what they have learned in the degree program, showing an interesting relationship with the perception of Australian final year students, while Australian professionals use in greater proportion than Colombians what they have learned in the classroom.

The survey asked entrepreneurs to rate their perception of the ease of finding trained and qualified engineers for the New Era. The results are shown in Figure 1, which shows their ratings on a scale of Easy, Very Easy, Difficult, and Very Difficult.

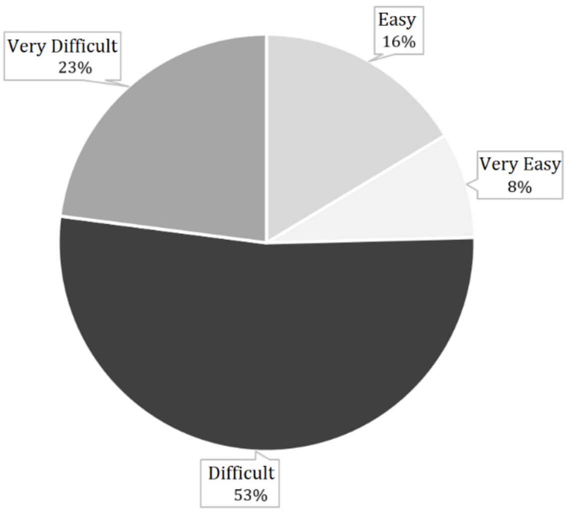

Figure 1. Employers' perception of the ease of finding trained and skilled engineers for the New Era

Although in both countries those who perceive the issue as easy or very easy recognize that the selection process requires them to resort to strategies that attract the attention of engineers, such as better salaries, industry location, or additional incentives, for most employers, it is difficult to find trained and skilled engineers for the New Era. But it is even more difficult to convince them to join. The reason is that many Colombians have current contracts with good salaries, while recent Australian graduates are not interested in joining the industry on a contract basis, because they prefer to work independently or on a fee-for-service basis.

Entrepreneurs were also asked about the value they place on engineering professionals having the ability to adapt to the production environment, use new technologies, be proactive and innovative, communicate, and integrate socially. Their appraisals are shown in Figure 2, rated as Indifferent, Not important, Somewhat important, Very important, or Essential.

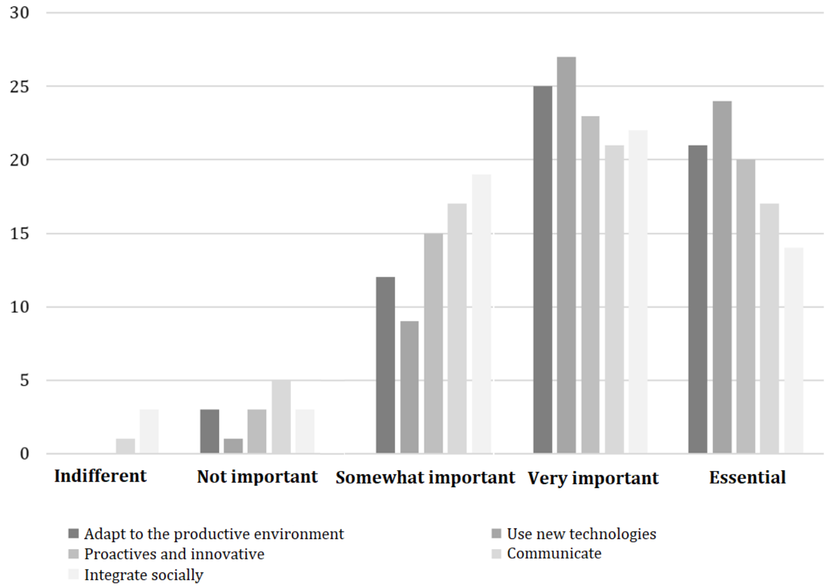

Figure 2. Employers' perception that engineering professionals possess certain skills

It is clear from Figure 2 that employers in both countries place a high value on engineering professionals developing these skills, which should serve to motivate academia to motivate students to develop them. It is observed that, for Australians, it is essential that professionals have these skills, because, as many of them express, this saves them time and money in the induction process during the linkage to the industry. For Colombian employers, it is important or very important, because they have become accustomed to developing induction processes for new employees, aimed at training them in these aspects.

5. DISCUSSION

Although the results found in this study can be differentiated in some aspects, in general terms they are very similar for each of the actors who participated. Among the actors, perceptions are subject to issues such as age, time of study, experience, and engineering discipline of performance and performance. This is confirmed by the fact that younger students still do not have a clear appreciation of many of the components covered by the survey, whereas, as they progress in their career, professional, or academic performance, they tend to express their opinions in a more organized and sustained manner. In addition, another aspect that makes a difference in the answers received is related to nationality, because Australian students and professors tend to value some components, which for Colombians do not seem to matter much to perform as a successful engineer.

One issue on which there was greater agreement is that assertive communication is highly valued in terms of its importance for engineering and the practice of engineering. On the one hand, senior students, practicing professionals, and business people perceive it as an essential aspect of engineering education and training, while professors and young students do not perceive it with the same value. This is because they have not yet experienced the professional performance of an engineer, and give greater importance to other components, such as practice and mathematics. This is not a general tendency, but it is very marked among Colombian actors, for whom these aspects prevail over interpersonal and assertive communication skills.

Regarding the components related to the process in the academy, that is, to the development of engineering studies, younger Colombian students and teachers value mathematics and assessment more highly than the curriculum and the teaching model, which receive better ratings from their Australian peers. Professionals, senior students, and business people in both countries agree that mathematics is not as important because new technologies allow for calculations and procedures needed in all engineering disciplines. Because of this, entrepreneurs and professionals call the attention of the academy to include more emphasis on training in new technologies for engineering.

On the other hand, when faced with the recurring question *When am I going to use this?* to the contents of the curriculum, it is striking that young Colombian students seem not to have received an adequate professional orientation in secondary education because the tendency in their assessments is that they have rarely or never asked themselves this question. On the other hand, their Australian peers tend to respond that this issue attracts a lot of attention. As for the professionals, in general, they think that they make little use of what they have learned in the course because they state that it is far removed from the reality of practice and professional needs, and they request that the curricula, practices, and contents be updated more frequently.

One of the aspects analyzed and investigated by the authors of this study refers to the supply of engineers trained for the New Era versus the magnitude of demand worldwide [9, 10]. So, to learn about the perception of employers, a question was included in this survey asking them about the ease with which they find and hire these engineers. The difference is that Australians have the possibility of offering them better salaries and remunerations, in addition to the fact that the language favors finding trained engineers who wish to work in the country. While Colombians have to bear the cost and time required to train them in what they need for the industry on their own.

Both Australian and Colombian employers perceive the use of new technologies and adaptation to the production environment as very important skills that engineers must develop. But Colombians also perceive it as very important that engineers possess structured communication skills and the ability to communicate in another language, as this offers them greater opportunities for the internationalization of their industry. Australians do not see this as very important, but they do see it as very important for them to be proactive and innovative because their interests are oriented towards being competitive in globalization.

6. CONCLUSIONS

Some similarities were found between respondents' assessments and between countries, especially in the need for the curriculum and content to be updated more frequently. The argument is that the lack of updated and proven knowledge makes it impossible for professionals to find good jobs, but also to compete with professionals from other countries.

To be a successful engineer, Australian actors perceive the so-called soft skills as more important: adaptation to the production environment, use of new technologies, proactive and innovative, communicative and social integration skills; while for Colombians, practical and teamwork skills are more relevant. This is because the business culture of engineering is very different between countries since in Australia students are educated and trained through a much more innovative teaching model than in Colombia.

These results should make the educational system take note and strive to listen to the voices of those who are most directly involved in the education and training of engineers. This issue should be a priority for any country because engineering is the area of knowledge that enables, facilitates, and sustains the development of nations. The reality of this statement is that the economies and societies considered to have higher levels of development, quality of life and culture are those in which engineering, innovation, and science are given priority and adequate budget.

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XXI

Teaching mathematics: A problem or an opportunity for engineering education in the New Era

Is teaching mathematics perceived as a challenge or an opportunity in the education of 21st century engineering students? To answer this question, a study was conducted in which students, professors, and professionals participated. The research method combined interviews, consultations, and face-to-face dialogues with universities, public bodies, professional associations, and businesses in addition to a literature review and surveys administered to students, professors, employers, directors, and engineering professionals. The primary results identified that mathematics is necessary but methodologies and teaching approaches must change, and that theory and practice must be harmonized to render mathematics pertinent to engineering education. The conclusion is that necessary to update content, teaching methods, and practices so that the digital generation comes to regard mathematics as an opportunity and not a problem.

1. INTRODUCTION

Since the beginning of engineering as a profession, mathematics has played a central role in student training, both as an entry requirement for universities and as an essential element of professional performance. It is for this reason that debates and analyses regarding the role of mathematics in engineering are a high-profile issue for governments, institutions, businesses, students, professionals, and society in general. If we accept the importance of mathematics in training processes, it will also be necessary to demand more appropriate training that would enable engineers to respond to social needs [1].

When we add to this the apparent crisis of a lack of engineering professionals and students [2], designing strategies for drawing in and retaining students becomes a matter of urgency. Therefore, because the myth of mathematics in engineering is always at the forefront when students choose a major, it is natural that academics, administrators, the industry, and the state focus their attention on this situation.

However, the role of mathematics in professional practice has changed radically in this century because of the emergence of computational mathematics as an innovative opportunity, stretching professors and study plans to their limits. Furthermore, mathematics develops transdisciplinary as explicit work, evolving as an activity that is distributed throughout work teams and supported by computers [3]. These scenarios have created a situation in which it is necessary to resolve the apparent contradictions regarding whether mathematics should be perceived as a problem or an opportunity for engineering in this century. The fact of the matter is that mathematics is and will continue to be critical in the training and formation of engineers. However, today, it is necessary to consider its multiple and various practical uses as well as the designation of the different disciplines that are included in the field of engineering.

The need for and the quantity of mathematics in a study plan should directly relate to the functions conducted by the professional. For this reason, the usefulness of mathematics for all types of engineers remains a topic of debate:

- What type of mathematical knowledge do engineers need today?
- Should mathematical knowledge be the same and in the same amount for all engineering programs?
- How should the essential minimum level for practice be characterized?
- What should mathematical knowledge be based upon?
- How is this reality affected by the development of computational mathematics?
- Should all generations be trained using identical content, teaching methods, and methodologies?
- When and how should mathematics be taught?
- Should programs that are not engineering programs include in their study plans the same mathematics that is taught to true engineers?

The issue here is that in this profession, it is necessary to use imagination, creativity, and free will to design and construct products that are safe and environmentally friendly. This is the responsibility of engineers who have been trained to solve social problems in a wide variety of manners. However, because of the increasing complexity of these challenges, today, we need engineers with a transdisciplinary understanding of the world and with specialized abilities and skills. Furthermore, given the broad diversity of disciplines into which engineering has been divided, it is necessary to have a deep understanding of the sciences that underpin engineering and develop new skills for applying this understanding. The point is that many of these sciences are taught as engineering sciences although their thematic core and professional profile are not engineering [4]. Therefore, these students do not need to develop skills at the same level as a true engineer.

If this type of problem is debated only by the so-called experts, it will be difficult to reach conclusions and make decisions that contribute to a solution. True leadership is required to stimulate and spread innovation in mathematical training in engineering and include representatives of all related communities. However, these teams should be small and practical so that conclusions are reached quickly and applied objectively. This chapter presents the results of research carried out by researchers and scientists from Australia, Canada, Finland, Norway, and Colombia, that posed the following questions:

1. What analyses should be conducted regarding the role of mathematics in the training and professional exercise of engineers?
2. How does the role of mathematics influence the decision to study engineering and subsequent employability?
3. What reflections can this analysis contribute regarding the methodologies used to teach mathematics?
4. What is the assessment of the role of the education system in this analysis?

2. METHOD

The research method combined interviews, consultations, and face-to-face dialogues with universities, public bodies, professional associations, and businesses in addition to a literature review and surveys administered to students, professors, employers, directors, and engineering professionals. The literature review was conducted using ScienceDirect, Scopus, and WOS. The author's trajectory, the research scope, the type of research conducted, and a comparison of the outcomes were considered, among other selection criteria.

Detailed reviews of the study plan and evaluation policies were not conducted. Although these factors affect training processes, they are only addressed tangentially. However, they were maintained as an objective for the next research phase. It should be noted that the students who participated in the study are of the digital generation and are currently in at least the third year of their studies. Table 1 presents the number of participants according to the role that each play in engineering. Figures 1 and 2 show the distribution per actor and per country, respectively.

Table 1. Actors participating in the research

Actor	Number	Objective vision for the project
Student	9397	Election of discipline; mathematical knowledge; usefulness of mathematics; curriculum integration; learning model; option teachers; technologies; ...
Researcher	38	Appreciation; prospective; contrast; experimentation; investigation; ...
Teacher	956	Professional experience; profession; investigation; updating of knowledge; technologies; methods, models, and didactics; ...
Employer	118	Specific needs; engineering disciplines; relationship with university; relationship with the state; prospective; work teams; ...
Professional	5765	Technologies; practical application; transdisciplinary; theory-practice relationship; updating of knowledge; investigation; ...

Director	218	Selection processes students and teachers; follow-up curriculum; academic practice; motivational strategies; self-appraisal; relationship with the company; relationship with the state; prospective; new generations; …
Public bodies	11	Regulation; tracing; normative update; analysis and discussion; university-business-state integration; …
Professional association	16	Regulation; tracing; normative update; updating of knowledge; integration with the university; integration with the company; …

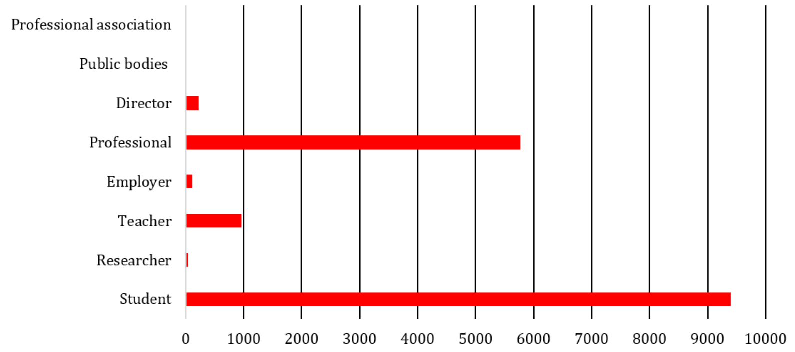

Figure 1. Distribution by type of actor in research

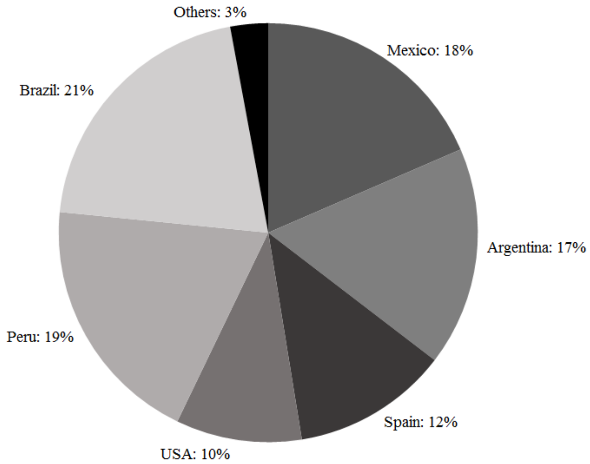

Figure 2. Percentage share by country

The research team is composed of researchers and scientists, with the support of master's students and research assistants who were responsible for compiling, transcribing, and documenting the interviews, searches, consultations, and dialogues with the participating actors. The total number of team members is as follows: 6 researchers, 4 scientists, 10 master's students, and 10 research assistants. Most of the responses (15858, 96%) were received through electronic form inquiries, in which the questions described above were raised. The other 4% (661) is distributed as follows: 160 interviews, 212 formal and informal dialogues, and 289 questionnaires. In addition, in the review of the literature, 118 documents whose content is related to the research topic, of which 62 met the selection criteria.

The work of compilation, systematization, and transcription was developed for 12 months with the permanent coordination of researchers and scientists. In general terms, this work was carried out in three phases: 1) debugging the information in the forms, which was carried out on the databases containing the answers, to eliminate redundant or incongruent data. This work was done by the students of masters because that information also is used in the development of their theses. 2) Transcript of interviews and dialogues carried out by the research assistants. Because the questions are the same as those contained in the forms, a database with the same structure was designed to systematize the results. 3) A compilation that is, taking the information in both databases to create one that can be used for the analysis.

The analysis and discussion of the results were carried out by the researchers with the advice of the scientists for four months. For the qualitative information database query algorithms were designed, to find parity by synonymy or disparity by antonyms in the data and to determine the type and number of actor that makes the affirmations. For quantitative information, a program was designed to extract the most relevant and useful data for research, such as age ranges, training levels, percentages, and standard and deviation indicators.

3. RESULTS AND DISCUSSION

3.1 Mathematics in the training and professional exercise of engineers

The conclusion of a large number of the participants (65%) is that engineering altered its course with the large-scale development of computers at the end of the 20th century: engineering ceased to be purely mathematical labor conducted by individual engineers and became a labor for transdisciplinary teams, globally distributed and mediated by software applications. The participants also concluded that some aspects of mathematics should continue to shape part of engineers' training, whereas other aspects should undergo considerable change in form and content, particularly in the manner in which they are taught in the classroom. At the heart of these assessments are debates regarding the boundaries dividing what is necessary from what is irrelevant in mathematics. In these debates, changes in content, quantity, and teaching methods are advocated.

In this sense, the statements of employers, professionals, and professional associations are summarized that these debates contribute little because they are dominated by pedagogues, mathematicians, and education administrators. Consequently, a belief has evolved in which mathematics is perceived to be the essential competition of engineering training and the engineering profession. The argument begins with the premise that mathematics develops the disciplined and logical thought that engineers need, whether for understanding problems or designing models. However, although students and professionals partially accept this valuation, several issues remain unresolved in the new century: the need to give mathematics a true meaning of integration with the rest of the courses and render its use visible in professional exercise. There are even doubts regarding what engineering and mathematics truly are.

42% of professionals tend to see mathematics as a support tool; many have had the need and the opportunity to directly involve mathematics in their work and consider that it provides them with confidence and helps strike a balance between their engineering skills and teamwork. The issue is that employers need professionals to develop other skills and abilities because computers perform cold calculations and developments. For students (38%) and professionals (27%), this should be part of the change because although previously engineers had to learn mathematics to respond to the practical purposes of their profession, the hope was that they would acquire a certain level of understanding of mathematics and that they would develop a logical manner of thinking that would differentiate them from other professions.

However, with the development of computation and its use as a calculation tool, the relation between the practical and the theoretical in mathematical training has been undermined [5]. Therefore, in agreement with employees and professionals, practical teaching should be more oriented toward systems modeling without decreasing the importance of theory: the right balance must be identified. In this same sense, 18% of professors affirm that the development of logical thought should be a formal aspect of education although a model has not yet been structured that allows professionals to do so. Likewise, students and some professors (younger than 40 years old) maintain that to develop or improve logical thought, some questions have yet to be answered because alternatives such as programming logic have emerged within the computer sciences.

Directors and administrators argue that they have had to respond to the demands of public bodies by decreasing the number of mathematics-related courses included in engineering curricula. In turn, these public bodies unofficially respond that this is because of pressure from international collectives based upon financial calculations and not real studies of professional and business needs. Some countries have even experimented with making it a degree requirement that students develop the mathematical skills necessary to practice their profession (this affirmation is confirmed by students). For 41% of professionals, the answer should not be a decrease in courses and content but rather the harmonization of training processes with the abilities and skills that the student possesses, both those required by the discipline (as determined by professional associations) and those expected by the industry (that harmonize with the abilities and skills expected by employers).

In this respect, professionals and professors argue that public bodies and universities should analyze the gap between the expectations of entrepreneurs and the reality of mathematical knowledge that students possess. However, 73 directors affirm that although they recognize that this is a reality, governments expect higher education to solve the problem. Along these lines, some authors in the literature review refer to this situation [6, 7] and affirm that the root of the problem is an obsolete education system that is patched together by each government. Furthermore, this gap does not appear to concern governments. Consequently, education at the elementary and secondary levels does not meet the expectations of institutions at the university level in terms of the mathematical abilities and skills that students should develop. In general, employers do not involve themselves in this debate because they consider the issue as being outside of their domain and because, for them, the most important thing is that professionals develop a holistic awareness of mathematics and not a specialty because each person's work needs are largely met by his/her analytical skills and spatial visualization.

33% of professors older than 60 years of age argue that the solution they have adopted is to follow the recommendations of the experts who participated in the discussion and analysis of this situation. These professors mention, for example, that study plans must include content that students should have previously mastered in school. Thus, students and younger professors cannot include university-level content in their courses, and as stated by employers, professionals only develop visions and theoretical compositions of something that they do not know how to apply using technology.

Another aspect of the problem that is manifested by 66% of professionals and their organizations is related to the diversity of engineering programs offered by universities and approved by public bodies. However, many of these programs are not engineering programs because they are more oriented toward providing professional or undergraduate degrees or because they could be offered as specializations. For the students (81%) and professionals (88%) in these programs, the mathematical content of the study plan has no meaning because in the workplace and because of their training, they will not need this knowledge to solve problems. According to these actors, the public bodies and professional associations are obligated to re-evaluate grading processes and the accreditation of engineering programs and analyze teaching processes. 17% of employers think that to establish proficiency in mathematical techniques in different contexts and dimensions, a more explicitly holistic and transdisciplinary focus should be adopted with the use of integrated software because this is the reality that professionals will encounter in the industry.

According to other studies included in the literature review [1, 8], this is a broad debate that has generated a struggle among related departments. This is because engineering departments do not want to remove these programs from the curriculum offered to students. After all, these departments are conferring engineering degrees. In addition, departments of art and other professions want to administrate these programs because their objective is to train professionals in specific areas. If we consider the need to change the mathematical content of these programs to include more general courses, the current resistance is understandable because the idea of change sparks fears among those who have dominated the training of engineers [9]. Other researchers [10, 11] affirm that given the differences between business needs and academic formation, we should opt for maintaining rigor and degree requirements for students of true engineering disciplines but become more flexible and re-orient the degree requirements for students who are not true engineers.

Added to the voices of these researchers are the voices of students (23%), professionals (39%), and employers (21%) who request that IT be included as a teaching method. According to them, the idea is not to replace the need for and the understanding of basic principles but rather to reap the benefits of the advantages that these tools offer and revolutionize the use and achievement of analytic techniques in engineering practice. The same applies in cases of symbolic manipulation using specialized software. However, 91% of older professors who have tried using these tools argue that the results do not sufficiently justify the restructuring of teaching models, although students experience the use of these tools with the same content, teaching methods, evaluative practices, and exercises that these professors have used throughout their teaching careers.

Likewise, 87% of directors are opposed to change because of the costs involved and because they still do not have a solid and common base of mathematical knowledge that would allow them to abandon a long-established teaching process. For this reason, some of the authors included in the literature review [7, 12] affirm that first and foremost, the system that this process is based upon should be innovative. That is, in the place of an education system there should be a training system. The objective is to involve all of the actors and components of the new system, that is, families, students, society, peers, schools, professors, universities, and administrations. Above all, however, government and state policies must be involved in this process with the objective that study plans, content, internationalization, and research contribute to forming individuals and training professionals.

Based on these opinions and affirmations, it appears that employers, professionals, and professors should be included in the dialogue regarding whether mathematics is a problem or an opportunity in the formation of engineers in this century because proposals for change should not be presented by pedagogues, scholars, and experts alone. Those who are involved in and familiar with the matter must contribute visions and interpretations based on their experiences, needs, and practices. In addition to analyzing the relevance of teaching models and methods in the classroom, these transdisciplinary groups should include topics such as the training and longevity of professors and administrators. The careful use of IT can render the application of mathematical theory before understanding the technique possible and even desirable. For this reason, the role of professional associations and government bodies, that is, their interventions to encourage universities to enact change, is important.

3.2 The influence of mathematics on the decision to study engineering and employability

87% of the participants argue that the important role of mathematics in engineering training must be recognized, both in the selection of a program and in a person's performance as a student and as a practicing professional. However, the participants also affirm that the level and content of the courses and the excessiveness of many professors add a level of strictness that often demotivates students. Since the end of the 20th century, there has been a decrease in the number of people interested in studying engineering [2], and mathematics is greatly responsible for this tendency. Among other things, according to professors and directors, this problem is the result of students commencing their studies without a sufficient knowledge base, for example, knowledge regarding the use of computers for mechanical calculations (employers and organizations of professionals), the obsolescence of curricula and the lack of teaching methods that might lure the digital generation (students and professionals).

Although this problem is part of the agendas of various discussions, the solutions have been to implement changes in study plans. However, it would appear that this objective is not being met [13], and in the meantime, there are lower rates of student admissions, retention, and graduation in engineering than in the majority of other programs. This generates a scarcity of professionals in a large portion of the world [14] at the same time that the industry requires more engineering professionals [15].

For professionals (53%), this situation is a result of institutions' training objectives differing from the needs of a world in which practical skills prevail over theoretical skills. 39% of employers have clear needs and objectives regarding the type of professionals that they require; however, 27% of students manifest their negative attitude toward mathematics, and 53% of older teachers and 63% of directors continue to uphold continuity in teaching models although the engineer's field of action is quite different from that which is portrayed in the classroom.

Therefore, the reality remains unidentified: the majority of institutions and professors expect professionals to make scientific and research contributions, whereas the industry requires engineers who are logical, practical, and quick to provide effective solutions. Simultaneously, public bodies maintain a complicit silence as if they were waiting for the problem to be magically resolved (students and professionals).

For some of the authors in the literature review, these points of view have no meaning in the reality of this century [16]. Although society expects engineers to solve its problems, governments do not structure clear policies in this area, and universities continue to train engineers with models that do not fulfill the expectations of students, nor do they respond to technological developments. It would appear that the mathematical community is not aware of the fact that engineers of this century must think and work in a context that is entirely different from that of the past century. Because of this, the debate regarding the quantity, timing, and form of teaching mathematics has become increasingly polarized, and the profession and exercise of engineering are losing their social importance while its image in the development of nations deteriorates.

Furthermore, professionals (69%) who believe themselves to be the most adversely affected by this situation ask for a solution to this divergence of perspectives because both positions imply a concept of the engineer that is based on different notions and needs. Employers argue that this debate has been reduced to something as simple as finding a definition that expresses what engineering is and what an engineer does. Researchers conclude that neither clarity nor unanimity exists about mathematics and engineering because analyses are misinterpreted and discussions regarding training processes do not arrive at clear and concerted decisions. The opinion of younger professors and many professionals is that a common language should be identified to achieve this consensus in a manner that facilitates the understanding of the various components.

In the meantime, while employers argue that in practice, computational mathematics is considered an opportunity that helps to expand the limits of engineering, students and professionals consider that academia is a problematic universe that destroys dreams. Directors defend themselves by noting the lack of preparation that students receive in school compared with the need to attract and retain students within departments. Additionally, the lack of interest in studying this discipline and the lack of skills that professionals can exercise arise because students do not develop abilities that allow them to fluidly and comfortably manipulate symbolisms and mathematical language.

For employers (45%), the problem may be addressed differently: universities should reconsider the usefulness of and need for academic mathematics in engineering practice given that its role has undergone substantial changes since the end of the 20th century. Mathematics is no longer the work of individual engineers themselves and has evolved into a transdisciplinary activity that is conducted by a team with the aid of computers. Employers use this argument to determine whether knowledge of mathematical theory is useful in the development of practice. Although professionals consider this argument to be valid, they contend that experience has demonstrated that mathematics has many diverse scenarios in the industry, which adds a high level of complexity to individual situations.

According to the researchers consulted [17], not only the direct usefulness of mathematical theory in practice but also its indirect usefulness for practice must be considered. That is, we must identify its formative role in the development of the engineer and, simultaneously, its contribution to the engineer's professional development. This analysis irremediably involves determining the content that mathematics contributes in both senses because although it is easy to demonstrate change in the direct use of mathematics in practice, it is not so easy to do so for its indirect uses [5].

Older professors, some directors (13%), and the majority of public bodies (78%) defend the place of mathematics and the teaching model in engineering as the most direct manner in which to develop the abilities and skills of engineers. However, 87% of students, 63% of professionals, and 61% of employers question the efficiency of the model and the teaching methods employed because this type of training is not what the new generation needs and is not compatible with technological developments and the needs of the industry. Some professional associations extend beyond this position and opine those professors are continuous and conservative and do not attempt to align the teaching model and methods with the needs of each generation of students. Researchers [11] maintain that public bodies and academia do little to update an obsolete education system that does not respond to the needs of this century.

For this reason, all actors must arrive at an understanding of whether mathematics is a challenge or an opportunity for engineering and discuss the strategies that should be implemented to close gaps: 1) between the mathematical skills that the schools develop and the needs of the universities, 2) between academic methodologies and students' expectations, 3) between the education system and the society of knowledge, 4) between technological development and curriculum content, and 5) between theory and practice in engineering. Furthermore, it is important to respond to the following:

- What type of mathematical knowledge do the engineers of this century need?
- How do we characterize the minimum level of mathematics that can be considered essential for engineering in this century?
- What should the selection of this knowledge be based upon?

- What is the effect of technological development?
- What, when, and how should mathematics be taught to the new generations?
- How can we respond to current needs about methodologies and techniques for teaching mathematics?

3.3 Reflections regarding methodologies and didactic techniques for teaching mathematics in engineering

For the majority of students (83%) and professionals (81%), education in engineering is currently undergoing a transition that includes debates regarding the teaching of mathematics for this discipline and the engineer's application of mathematics. The majority of professors, mathematicians, and pedagogues who participated in these debates were trained in an age in which the tools used today did not exist and computers had not become popularized in educational and engineering practice. Currently, these developments are common and offer new and better services for the work of engineers [18]. Therefore, questions arise regarding the value, relevance, and necessity of using the methodologies and teaching techniques that these professors use.

According to Nethercot [19], engineers do not need to be proficient in outdated techniques, nor do they need to perform analyses on paper because this is what computers are for. However, although engineers must know how to validate the machine's results, this does not justify the use of old books or teaching methods that revert to pencil and paper if these techniques have no practical use in the real world.

It remains necessary for engineers to develop fundamental mathematical abilities to practice their professions, such as number sense, logical-interpretative and abstract thinking, the use of scales and orders of magnitude, mental calculations, and engineering principles based upon mathematical ideas [15]. However, some abilities have changed or disappeared, as affirmed by students, professionals, and some employers, including manual calculation, the memorization of formulas and equations, analysis on paper, and solitary and single-disciplinary work. In addition, different content can be relevant at different times in engineering. For example, the calculation is important for appreciating basic principles; however, according to professionals, the calculation is rarely required in practice.

Despite this lack of use, calculation remains a component of all of the curricula of the discipline because, older professors argue, it develops analytical perception. Students and professionals agree that this is a valid point but that as a result of the methodology and teaching techniques used by professors, this objective is not achieved. On the contrary, students are discouraged by the study of calculation.

When analyzing the responses of 62% of practicing engineers, a positive valuation of the power of mathematics is observed. However, the responses draw attention to limitations in practice. Among other things, the respondents describe mathematics as an instrument for modeling, calculating, predicting, and designing and associate it with its characteristics such as reliability and usefulness. If computational mathematics is not used, models can be expensive because of the time that manual calculations require or because the problem is too complex to solve on paper. Controversy exists regarding this point because whereas professors argue that they were trained to do calculations in this manner, students and professionals argue that that was another time and that today we have technological developments, so why not use them? For researchers [20, 21], this clash between different generations in which each side wields different ideas and points of view arises, among other things, from the obsolescence of the educational system, a lack of updating, and scant understanding between the two sides.

Amid everything, an agreement evolves: mathematics is necessary for engineer training. The problem arises because there remains no clear definition of engineering, nor has it been established which of the programs that are currently offered as engineering programs are truly disciplinary specializations or professions [22]. For students (62%) and professionals (55%), the issue is that mathematics should extend beyond the simple communication of concepts, ideas, and information based on the text in a domain of processes and abstract concepts with little or no real application. Participants observed that if professors were to use methodologies and teaching techniques that are appropriate for the generation being trained, disciplined reasoning could be developed and potentiated in a manner that demonstrates both theoretical and practical potential.

The majority of the actors of this study appeared to agree on this point, although, for the professional associations, the particular meaning of each term became another point of disagreement. For example, the professional associations argue that there is no consensus regarding what engineering, mathematics, teaching, training, and evaluation are and that as long as these simple matters remain unresolved, the theoretical and practical universes of mathematics will be a central issue of debate.

Although this percentage of engineers do not perceive mathematics as a problematic area in engineering, they do believe that there is not much need for theoretical knowledge in the practice of engineering. This is because, among other things, the industry expects engineers to have abilities and skills for understanding and using the necessary technology; however, in addition to this flaw, the industry observes deficiencies in engineers' verbal and written communication. 57% of employers, however, do not understand why academia continues to teach mathematics that the professional does not need, advocating that the engineers of this century should be more social, human, and philosophical than automated and programmed because what engineers need is the ability to communicate their thoughts to manage knowledge, work in transdisciplinary teams and seek multi-dimensional solutions on their own. Because computers are used for all of the necessary calculations and models, what employers need is engineers who are trained to use software, understand algorithms, and formulate sensible solutions and sensitive interpretations.

Another perception of professionals is that engineers should trust in the calculations of machines, which requires a certain level of mathematical theory. Nonetheless, the contents are nearly completely theoretical, the methodologies and teaching techniques are obsolete, the application is conducted in the form of exercises rather than problems or projects, and professors are not up to date on the needs of this century. These assessments confirm the findings of other studies in which, for entrepreneurs, the mathematical knowledge required to solve the great majority of challenges that the industry faces is reduced to arithmetic and statistics [23] because computers can manage the rest.

Employers said that a balance must be struck between engineer training and business needs. That is, not all businesses require engineers with broad analytical skills because the majority of problems require a combination of these and other skills. This is a warning to academia that it should not train engineers as if they were running a production line, unaware that the level of theoretical-practical skills leans in different ways in the real world [7].

Another positive aspect expressed by study participants is related to the initiatives in some institutions to develop engineers' knowledge management abilities. According to 41% of directors, beyond the mathematical and scientific knowledge for which professionals have little use, professionals must access, compile, analyze, and manage knowledge that is potentially more relevant to their practice. This concern is consistent with the increase in knowledge. For example, in the 19th century, one could study all of the existing technology in a single course.

Today, however, various courses are required and even then, do not manage to cover all of the existing technological knowledge. A less positive aspect for students (52%) and professionals (38%) occurs when this argument is used to create programs in specific areas of engineering, many of which are specializations that engineers can access whenever they might need this knowledge.

Conversely, 50% of directors argue that because of this situation, they do not know what to teach because the industry asks for specialized professionals and, of course, a traditional program cannot produce numerous specializations. Professionals argue that they do not need to study for five or six years to graduate in a sub-specialty of engineering because they can achieve such specialization independently. The current question is whether the university should concern itself with training professionals and forming individuals instead of educating, training, and developing skills because, in this century, more trained professionals are required who can manage the amount of knowledge available and who are capable of putting that knowledge to use in their work [24].

3.4 The role of the education system

During the Industrial Revolution, it was expected that engineers would learn much mathematics and develop skills to apply in factories [1] in addition to using mathematics as a logical manner of thinking, acquiring thinking abilities, understanding the physical world, applying intuition, and coding information, among other things. In that era, science had convinced society that mathematics was the intellectual muscle of the Industrial Revolution; thus, professionals were required to take many theoretical courses to be able to use mathematics. That is, theoretical aspects were then more important than practical ones, and students were expected to take numerous courses before practicing their profession [3].

According to 47% of employers and 41% of professionals, although theory is currently important, technological developments indicate that the relation between theory and technology is direct and that the two should be addressed together. Employers and professionals agree that the engineer's reality is not navigating through books in search of equations to compute proofs on paper because computers do such work. What engineers need is to develop their capacity to interpret the meaning of mathematics, not to memorize equations and apply them as an automaton would. This is the area in which the education system should focus its attention. Researchers argue that such a course of action would not eliminate manual work but would achieve a balance between theory and practice while autonomously administrating and managing the necessary knowledge [4].

Such a change would engender substantial modification to the system, ending the education system and implementing a training system [7]. Furthermore, engineers’ interpretation of the meaning of mathematics in communicating their work is not something that has decreased with technology. What is occurring is that engineers no longer require pencil and paper for computation because they make themselves understood with a spreadsheet [17].

Another generalized consensus among those interviewed in this study is that engineers should receive a rigorous mathematical education not because they need mathematics or use it in their professional exercise but because mathematics develops a different manner of thinking: ingenuity, logic, abstraction, dimensionality, and the ability to integrate and de-integrate what is required. In this sense, the assessment of professionals (53%) and students (51%) is that older professors do not abandon some courses, such as Euclidian geometry, because they were useful in their time, even though, today, such courses can be replaced by technology. Current thinking is that it would be better to develop other abilities and skills that society demands and leave the mechanical calculations to computers. In current discussions regarding the education system, employers remain unable to reach an agreement because positions are uncompromising and governments have not wanted to intervene as they should.

87% of students and 71% of professionals propose, for example, that they be shown the theoretical potential of mathematics by practical problems, not exercises; that the theoretical potential of mathematics is integrated into other courses; those professors have experience in the industry; that professors value and improve students' knowledge; and those professors utilize innovative teaching techniques and evaluation.

In addition, our respondents propose that this area be practiced to learn it, that such practice requires time and pauses in the learning process to assimilate and understand, and that it is necessary to consider whether logical-interpretive and abstract skills may only be acquired or developed by studying mathematics. Some respondents commented that this ability was achieved with computer programming and suggested an appropriate integration of traditional and new courses to structure a curriculum that attracts students. There is no easy solution, partially because professors do not appear to be willing to change and cling to traditional teaching techniques and methods and partially because public bodies do not intervene or patch up the education system with the plans of the incumbent governor [13].

In this landscape, researchers ask what can be done because it is not sufficient to motivate students to enter programs, encourage them to remain, and provide them with sufficient training [12]. It is also necessary to address questions such as those mentioned by students, professionals, and employers: that regulation and control bodies incorporate new conditions to open programs, accredit them, or keep them running. According to directors, the demands of research, education, and services create a scenario in which the directors do not know what their priorities should be, how to hire, or what type of professor responds best to these needs. Directors mention, for example, that public bodies encourage the hiring of professors with a Ph.D. to improve the quality of education, and although hiring a Ph.D. has been suggested as a requirement, no evidence indicates that levels of education increase following such hiring. Furthermore, the majority of these professors have a research orientation, suggesting that their experience in the industry is nearly non-existent and that teaching is not a priority for them.

Another argument of directors is that universities should be restructured to reduce costs by sharing resources and merging departments. Such restructuring presents a new challenge because deciding who will be in charge of, for example, mathematics courses becomes a point of debate. Thus, universities must choose between taking advantage of integrating mathematicians or hiring engineers, which would increase costs. Professionals argue that they cannot view this as an imposition because it appears that directors only think in terms of the economic implications when they should be considering the importance of the profile of the person who teaches mathematics in engineering. Interest decreases even more because the number of students who are admitted renders this matter unprofitable. For professionals, this scenario leads to mathematicians taking these courses with a theoretical vision because they do not have the training or engineering work experience, and hence, students do not receive sufficient orientation regarding the importance of mathematical practice.

The authors consulted here add that the education system assumes that teaching mathematics is a matter to be addressed by higher education [9, 16], where students complete the process of preparing for employment. The issue is that mathematics cannot be limited to only one educational phase because it is the responsibility of educational institutions at all levels: elementary, secondary, and higher education institutions. 67% of professors consulted here affirm that the university finds itself in a difficult position because of the level of mathematical understanding of the students admitted: those students have not developed fluidity or precision in their performance of calculations, their analytical skills are deficient, they do not have a structured concept of mathematics and its usefulness, and the majority of the students arrive expecting that professors will demand no more of them than what they are accustomed. For this reason, directors defend themselves, arguing that to retain students, the university has had to use various strategies for evening out their mathematical knowledge, such as personalized advising, offices that provide orientation, and psychological counseling, all of which require an additional financial investment.

Another subject addressed by professionals (49%) and various authors from the literature review is that not all engineering problems can be attributed to the teaching of mathematics. Respondents mention, for example, the decreasing popularity of engineering in recent decades, the lack of state support, an obsolete educational system, professors lacking professional experience, out-of-date teaching methods, and the belief that all students possess the same level of knowledge. The majority agree that the mathematics being taught today is not the most appropriate for all engineering programs and that differentiation is required for the curriculum to be useful to students. This problem is not new to the authors, who came to identical conclusions in previous studies [1, 6]. The concern is that this problem grows with every new generation because each generation’s perception of the world and manner of prioritizing events in their life plans are quite different from the manners of previous generations.

Furthermore, irregularities are perceived between what students expect and what they achieve; their learning model is different from that of any other previous generation because students currently have within their reach revolutionary technological developments. These generational changes have been slow, although the state, university, school, society, and even education system have not realized this in time to institute the necessary reforms. Mathematics professors, however, require time to structure teaching models and methods for each generation, and if such changes in the system do not occur, their lack will further complicate the problems that have become apparent.

Furthermore, researchers relate the myth of mathematics to students because schools and society have convinced students that mathematics is the most important component of their education and that it is extremely difficult [20]. Directors refer to this as something that the university should address but state that the process of solving the problem takes time and resources and that they cannot, therefore, ensure its success. The solution is not last-minute *shock* plans, crash courses, or motivational talks because the problem should be resolved by the education system in schools; the myth cannot be eliminated in one educational period.

48% of students and 39% of professionals repeatedly refer to generational differences between professors and students in the sense that such gaps result in the distancing of one from the other;

for professors, mathematics is the most important thing, whereas students see it as merely another course. Professors affirm that they are responsible for what they teach and do not have time for other obligations, such as curricular integration with other courses. Students affirm that they live in a digital world that integrates everything that they need but that at the university, they take island courses that they must simply attend to pass exams and nothing more. However, their same restless spirit signals to them that something is missing: Where can students make the most of mathematics? Professionals respond that professors are responsible for advising students and accompanying them in the process of transforming information into knowledge that students can use to solve problems.

These two generational universes must find a common ground upon which to join their interests, intentions, and skills because new symbolisms and requirements in engineering and mathematics are overwhelming them. Employers and professionals argue that this matter should be reviewed in engineering education based on content, methodologies, methods, and teaching techniques because the complex problems of this century require professionals with a global, multi-disciplinary, and multi-dimensional vision. Researchers, however, ask the following questions: 1) Given the technological development of this century, to what extent should pencil and paper continue to be used as the primary teaching tool for the development of mathematical skills? [26]; 2) About the abilities and skills of the current generation of students, should mathematical memorization continue to be used as a learning indicator? [13]; 3) Considering student diversity in the classroom, should students be treated as if they were a homogenous group with identical skills and intentions for engineering? [12]; 4) What are the generational differences in attitudes between professors and students regarding the value of mathematics in engineering? [17].

4. CONCLUSIONS

Consensus must be reached regarding clearly defining what engineering is to organize the programs offered and structure mathematical content that is appropriate for these programs.

There is a general agreement that engineering students must develop mathematical skills, the concern being what type of mathematics they need and when.

The education system requires such profound restructuring that the majority of study participants agree that it would be better to create a new training system that performs as a system and that demands that each of its sub-systems assume responsibilities.

Mathematical education, regulation, frameworks for admission and graduation, updating of professorial and professional practice, the articulation of mathematics with other courses in engineering, and an evaluation framework for determining the development of skills and abilities should all be clearly defined.

Theoretical and practical content is a priority because academia and the industry are far from a consensus. For academia, engineers must be proficient in mathematical conceptualization. In the industry, engineers must develop logical-interpretative and abstract skills to analyze, understand, and use the results of computational calculations.

The methodologies and techniques used to teach mathematics must be evaluated because students today have different expectations from previous generations, and it is necessary to motivate these students to study engineering. Modifications should include a mental shift in professors, a broad restructuring of study plans, internationalization of content, improvement of the social appreciation of engineering, and regulation of professional exercise and salary level.

The New World Order that followed the technological revolution of the 20th century affected all areas of social development, including education. Today, it is necessary to consider technology as an ally in teaching and potentiating mathematics, both in schools and in the industry. It is necessary to extend beyond pencil and paper calculations to computational calculations because this tool is used daily by engineers.

Engineering should once again become a profession that is highly valued and recognized by society and the business world. This value and recognition have been lost because of an excessive number of programs, many of which were not engineering programs, and because of the lack of leadership and state policies. Furthermore, professional associations do not assume their responsibility and must align with public bodies and universities to give engineering programs continuity and endorse their initiatives.

If professors continue to work with exercises and not problems in mathematics training, students will not improve and innovate their IT knowledge. A slightly more attractive alternative could be the use of project-based learning PBL, which creates challenges so that students may integrate mathematics into the other courses that they take.

The general perception of students in this study regarding mathematics in engineering study plans is that mathematics is an unnecessary imposition. This attitude is partially the result of the number of programs offered as engineering that in reality are not engineering programs and partially because the nucleus of mathematics is structured around the study plans of programs that are true engineering programs.

Engineering is an area of knowledge that has diverse inter-relations with other areas. Therefore, engineering should train its professionals to utilize the principles of complex thought such as transdisciplinarity and multi-dimensionality.

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Transdisciplinary Science

Edition 1

The book is set in the context of adaptation to major changes in the New World Order, a field increasingly characterized by transdisciplinary discourse and methodological experimentation. An adaptation that takes place locally as well as globally, so that the integration of knowledge and the production of relevant solutions to the challenges must be considered especially urgent. That is the complexities of adapting to the New Era demand relevant knowledge, coming from diverse disciplines and perspectives, and application that bridges the gap in disciplinary science. As evidenced in this book, Transdisciplinary Science is possible, and the reader will find common factors and patterns that make it an attractive model for scientists, researchers, and scholars to pursue social adaptation, despite the practical and epistemological challenges facing humanity in this century.