Semiconductor and Chip Capability Index to Transform Engineering Education

Jose Texier

Assistant Director of "The Latin American and Caribbean Consortium of Engineering Institutions" (LACCEI). Computer Engineer UNET (2002, Venezuela). Master of Computer Science, University of the Andes (2008, Venezuela). PhD in Computer Science from the National University of La Plata (2014, Argentina). Invited Professor and Researcher Universidad Nacional de Chilecito (2014-2023, Argentina). Ex professor UNET (2003-2015). The research areas are framed in Digital Libraries / Institutional Repositories / Open Science, Compilers and Interpreters, Natural Language Processing: *. Orcid: http://orcid.org/0000-0003-0176-6625 *. Google Scholar: https://scholar.google.com.ar/citations?user=kUQ1boMAAAAJ&hl=en&oi=ao *. ENTER (EngineeriNg educaTors pEdagogical tRaining): 2311001032

Dr. Maria Mercedes Larrondo-Petrie, Florida Atlantic University

Dr. Larrondo Petrie has a Ph.D. in Computer Engineering and is a Professor in the College of Engineering and Computer Science of Florida Atlantic University. She is the Executive Director of LACCEI (Latin American and Caribbean Consortium of Engineering Institutions, and a Titular Member of the Pan-American Academy of Engineering.

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Fernando Zorto Universidad Nacional Autónoma de Honduras fernando.zorto@unah.edu.hn 0000-0003-0176-6625	Jose Texier LACCEI United States texier@laccei.org 0000-0003-0176-6625	Maria Larrondo-Petrie Florida Atlantic University United States petrie@fau.edu 0000-0003-2354-4986	Ricardo Hausmann LACCEI United States ricardo_Hausmann@hks.harvard.edu 0000-0002-9418-0019

Abstract:
This paper presents an analysis of the semiconductor and chip sector through a capabilities development index for universities. The aim is to provide a tool that contains the necessary index to measure universities' ability to adapt, create, and transfer knowledge and technologies to industrial and economic sectors, based on their research, development, innovation, and entrepreneurship (R&D+i+e) capabilities. The proposed index integrates key indicators from various domains, grounded in scientific theories and approaches presented by Lall, Meyer et al., and Powers, such as: scientific production, human resources, legal agility, entrepreneurship, economic capacity, and technology transfer. Using the semiconductor and chip industry as a case study, the paper outlines the methodology for applying the index and assessing university capabilities in this sector, across five universities in Central America, identifying their strengths and weaknesses. The evaluation reveals how universities contribute to technological development and economic competitiveness, emphasizing that the index can and should be adjusted to the characteristics of each industrial or economic sector. In this regard, the weighting of indicators may vary, and some indicators can be removed or added according to the defined context. This index provides a strategic tool to guide universities in their continuous improvement, aligning their research and training programs with the industry's needs. The study concludes that universities play a key role in the transformation of engineering education and the promotion of sustainable economic development through strategic innovation.

Keywords: capability, index, transforming, engineering, education, semiconductor, chip.

Introduction

In the contemporary world, there is still a gap in economic development between different regions, which is largely due to economies' capacities to develop highly complex goods and services that allow them to compete within global value chains [1], [2]. According to Hidalgo and Hausmann [3], one of the key elements to achieving this productive complexity is Know-How, defined as the practical and theoretical knowledge necessary to create and make complex goods and services available to the masses. Know-How refers not only to technical knowledge but also to the ability of an organization to apply such knowledge efficiently, and its continuous development is essential for the competitiveness of any sector or economy [4], [5].

The transformation of an economy into one based on knowledge is considered a crucial driver of change for sustainable development and economic progress [6]. In this context, engineering education plays a key role, since universities, not only as educational centers but also as fundamental actors in the transfer of technology, must adapt to train qualified professionals who can generate innovation in strategic sectors. In countries such as China, Japan, Singapore, Vietnam, South Korea, Taiwan, Malaysia, and Thailand, investment in research and development (R&D) has been a key strategy for creating innovative and highly complex products, allowing them to compete globally, especially with North American and European products [7], [8].

Within this context, sectors such as the semiconductor and chip industries have emerged as examples of complex technologies that have been driven by intense research, development, and innovation (R&D&I) processes, both in private and public environments, mainly in universities and research centers. These technologies not only have high innovation potential but are also crucial for the economic competitiveness of the regions that develop them [9].

The intention is to promote local and regional economic growth through productive knowledge, using the semiconductor and chip sector in Central America as a case study (of this study). Therefore, through this approach, universities in the region that have the most appropriate capabilities to lead the development and transfer of technology in this field are identified, but they can be applied to any sector and region.

This study proposes a comprehensive model to measure the capacity of engineering universities to analyze the semiconductor and chip sector, evaluating their ability to adapt, create, and transfer knowledge and technologies with economic impact. The model, based on a Capability Index, allows for the identification of institutional maturity levels in key areas such as research, development, innovation, and entrepreneurship (R&D+i+e). Therefore, the objective is to analyze the semiconductor and chip sector through a capabilities development index for universities, aligning their capacities with the sector's demands to promote local and regional economic growth, fostering innovative collaboration between engineering education, industry, and governments through the creation and transfer of knowledge and technologies.

Literature Review

The proposed index to measure the capacity of universities and therefore of countries to transform engineering education is composed of five key categories of indicators: economic, legal agility, scientific and technological production, human resources with scientific impact, and entrepreneurship. These indicators are based on scientific theories and approaches presented by Lall, Meyer et al., and Powers

[10], [11], [12]. The three approaches presented by the authors offer a robust framework to understand the intersection between university/country technological development and its local/regional economic impact, and therefore will be the most appropriate for the proposed approach.

Lall [11] asserts that the development of technological capabilities in nations, and consequently in institutions of higher education, does not occur in isolation, but is profoundly influenced by the economic context and public policy (governments). The author highlights the importance of the fact that if skills are not found locally, it will be necessary to import them. This is expensive, and the local workforce will have to quickly acquire this skill. Lall also indicates that local innovation capabilities can be key catalysts for sustainable economic development; that is, that research and development are ways to achieve the adoption of technological capabilities..

The Triple Helix model, introduced by Meyer et al. [10] and depicted in Figure 1, illustrates the interconnected relationships between universities, industry, and government as catalysts for innovation. This framework posits that universities serve not only as knowledge creators but also as conduits for technological advancements that propel the industrial sector and enhance economic competitiveness. The examination of patents and academic inventors' involvement supports the notion that universities, through their innovative capabilities, can become crucial catalysts for entrepreneurship and economic development in advanced industries, thereby invigorating regions and/or nations.

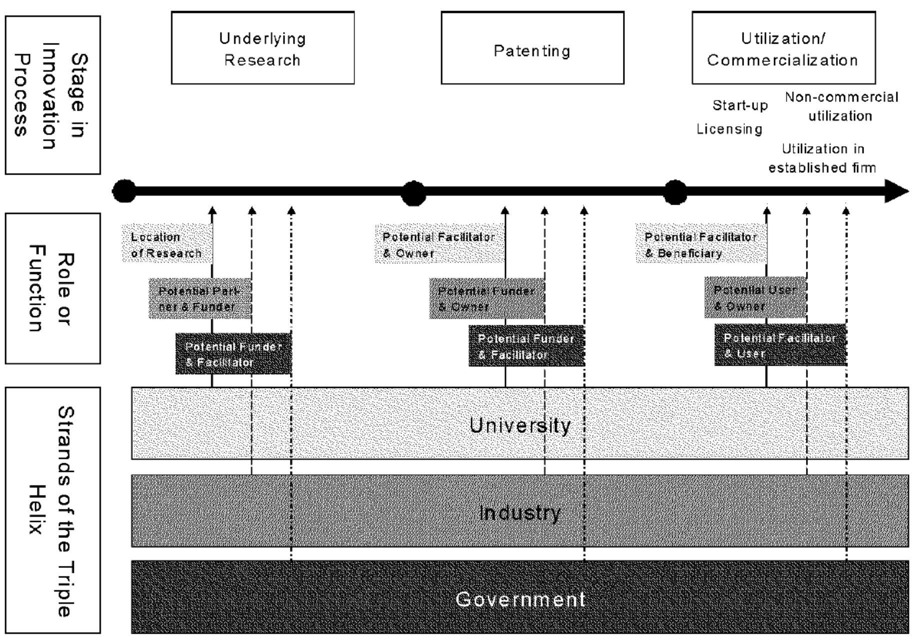

Figure 1. The Triple Helix and the innovation process. Fuente: Meyer et al. [10]

Finally, Powers [12] focuses on how universities adapt to market demands through the commercialization of their research, a phenomenon known as *academic capitalism* [13]. This process implies that universities not only generate knowledge but also apply that knowledge by creating technological companies and collaborating with the private sector, that is, creating patents and executing licenses. Therefore, university technology transfer can be measured using three major dependent variables: patents maintained, licenses executed, and income generated by licensing. Likewise, Powers argues that the internal resources of universities, such as the quality of research and human capital, are key factors for success in technology transfer.

These three theoretical approaches suggest that technological development and knowledge transfer from universities not only directly affect the industrial sector but also have the potential to transform the regional economic structure, improve competitiveness, and generate a positive impact on economic growth. Therefore, the five indicators presented below were selected based on theoretical approaches to assess how universities contribute to local and regional economic development through their capacity to generate, transfer, and commercialize advanced knowledge. Appendix I provides a more detailed view of the proposed universities' capability index using these indicators.

First, **economic indicators** assess the relationship between universities' technological development and regional economic growth. Research and development (R&D) expenditure as a percentage of GDP; high-tech exports; and Science, Technology and Innovation (STI) policies that boost technological capacity are considered. These factors are linked to universities' role in increasing economic complexity and fostering regional dynamism.

Legal agility indicators measure universities' ability to adapt quickly to regulations and policies, facilitating the commercialization of their research and the development of new technologies (patents), that is, ensuring that institutions operate in a legal environment that favors innovation and entrepreneurship, that is, intellectual property. Therefore, the process of filing patents, which involves rigorous legal steps, should be reflected in the proposed capabilities index, as discussed in Powers' approach [12] to research commercialization.

On the other hand, **indicators of scientific and technological production** focus on the quantity and quality of research generated by universities. This component reflects the institution's capacity to produce knowledge that is valuable for industry and society, aligning with Meyer's proposal [10] on university-industry links.

As for the **indicators of human resources with scientific impact**, they measure academic talent and the capacity of researchers to lead technological projects that can be transferred and applied in the industrial field. The quality of its professors and researchers is fundamental to the success of a high-impact technological transfer, as highlighted by Lall [11] in his analysis of the development of technological capabilities in countries.

Finally, **entrepreneurship indicators** measure the university's capacity to generate technological companies. This includes institutional support for the creation of startups and spin-offs through incubators. Therefore, we evaluate the number of startups and spin-offs created, which reflects the capacity to commercialize technologies and innovations. These indicators are key to promoting innovation, as described by Powers [12].

Analysis of the Semiconductor and Chip Sector

The development, innovation, and knowledge transfer [14] within the semiconductor and chip industry are significantly influenced by universities' capabilities to generate knowledge that addresses real-world challenges [15]. In this context, the capabilities index proposed in this study aims to assess the ability of institutions to adapt, create, and transfer technologies with a direct impact on local and regional economic growth in strategic sectors, such as semiconductors, but can be adapted to another sector and region [16].

The semiconductors and chips industry, a driving force behind numerous technological advancements, faces considerable challenges, including increasing demand for more efficient components and geopolitical tensions within the supply chain. As advanced economies continue to dominate semiconductor production, developing regions, such as Latin America and the Caribbean, have a unique opportunity to enhance their capabilities in research, development, innovation, and entrepreneurship (R&D+i+e).

Universities must act as catalysts for this transformation by adapting their educational and research models to the needs of a knowledge-driven economy and aligning with the demands of key industrial sectors [16], [17]. Consequently, the application of the proposed index to the semiconductor and chips sector is presented, focusing specifically on Latin America and the Caribbean (LAC).

Before delving into the index, it is essential to understand the semiconductors and chips supply chain as a multifaceted process that encompasses seven stages [18], [19], [20], [21]: raw material extraction and production, wafer fabrication, chip design, chip manufacturing, assembly, testing, packaging, component distribution, logistics, and, ultimately, the manufacturing of electronic products or devices. It is important to emphasize that semiconductors are the fundamental materials enabling the fabrication of chips, and the chips, in turn, represent the final product integrated into virtually all modern electronic devices (smartphones, servers, automobiles, industrial equipment, etc.) [21], [22], [23], [24]. It is crucial to emphasize that education, research, and development play transversal roles across these stages.

To address the transformation of engineering education within the semiconductors and chips sector, it is imperative to identify engineering programs that are aligned with the various stages of the supply chain (Table 1), and subsequently assess the required capabilities based on the proposed index for the semiconductor sector in LAC, which serves as a case study for this study.

Table 1. Engineering Programs & Supply Chain Semiconductor and Chip. Source: Own.

Supply Chain Stage	Related Engineering Programs
Extraction and Material Production	Mining Engineering, Chemical Engineering, Materials Science and Engineering
Wafer Fabrication	Chemical Engineering, Materials Science and Engineering, Manufacturing Engineering
Chip Design	Electrical Engineering, Computer Science, Integrated Circuit Design
Chip Manufacturing	Electrical Engineering, Manufacturing Engineering, Applied Physics
Assembly, Testing, and Packaging	Electrical Engineering, Systems Engineering, Quality Engineering
Distribution and Logistics	Industrial Engineering, Logistics and Transportation, Business Administration
Electronic Device Manufacturers	Mechatronics Engineering, Electrical Engineering, Industrial Design

Methodology

This study adopts a comprehensive methodology to assess the capabilities of universities in the context of the semiconductor and chip sector, specifically focusing on "Chip Manufacturing and Design" in universities across Central America. The methodology is built upon scientific theories and approaches proposed by Lall, Meyer et al., and Powers [10], [11], [12] , whose frameworks offer a solid foundation for understanding the intersection between university-based technological development and its local or regional economic impact. These theories provide the appropriate structure for evaluating how universities contribute to the growth of advanced industries.

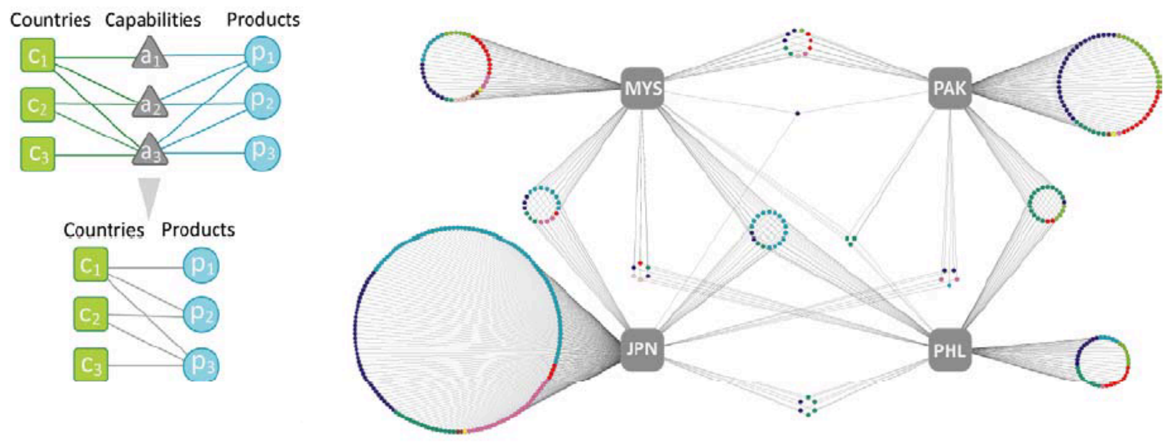

Figure 4. Capabilities and examples: Malaysia (MYS), Pakistan (PAK), Philippines (PHL), and Japan (JPN) in 2000 [3]

The Universities Capability Index is aligned with the theoretical model proposed by Hidalgo & Hausmann in their work on "Quantifying countries' economic complexity" (see Figure 4), where they suggest that a country's capabilities can be compared to letters, which are the fundamental units required to generate products. Products resemble words, formed by the combination of capabilities (letters). In other words, the more capabilities (letters) a country possesses, the greater the diversity of products (words) it can generate. Therefore, a country can be viewed as a Lego set, with its unique collection of capabilities (pieces) being assembled to create products. As a result, countries with more capabilities are better positioned to develop more complex products.

For this reason, an index is proposed that is composed of five macro indicators that measure the ecosystem and its different capabilities that a university has to achieve the creation of more competitive products and services from the perspective of one or more activities of a specific value chain. Table 2 shows the indicators with their respective weights for measuring the university's capacity to innovate in a specific activity in a value chain. References for all proposed indicators can be found in Appendix II.

For this purpose, it will be necessary to normalize the value of the sub-indicator using the following formula:

$$X_{norm} = \frac{X - X_{min}}{X_{max} - X_{min}} \qquad \textbf{Eq. 1}$$

Where X is the current value of the indicator by university if the indicator is positive, **X_min** and **X_max** are the minimum and maximum values of the expected range. If the data has a negative trend, that is, the lower value is better than a higher value, it will be necessary to use the following formula:

$$X_{norm} = 1 - \frac{X - X_{min}}{X_{max} - X_{min}} \qquad \textbf{Eq. 1}$$

Table 2. Weights of the indicators of the Capability Index. Source: Own

Indicator	Weight
Economic Indicators	10%
Legal Agility Indicators	10%
Scientific and Technological Production Indicators	35%
Human Resources Indicators with Scientific Impact	25%
Entrepreneurship Indicators	20%

Then, to calculate the normalized value of the index, it will be necessary to weight it with its respective weight provided by Table 2, having the following equation:

$$\beta = \sum_{i=1}^{n} P_i * X_{norm,i} \qquad \textbf{Eq. 2}$$

Where β is the capabilities index, ***P_i*** is the weight of indicator **i**, where ***X_norm,i*** is the normalized value of subindicator ***i***. To rank the indices, a descending criterion will be followed, assigning greater priority to those with higher numerical values, since these reflect a higher level of performance or relevance in the index.

Results

The capabilities index was applied to evaluate the capacity of five engineering universities in Central America to generate, transfer, and apply technologies within the semiconductor and chip sector. To begin, a pool of potential universities was identified for analysis, focusing on their capabilities in creating goods and services related to chip design and manufacturing. **LACCEI**, with its 232 member institutions, of which 68 are active, was instrumental in selecting the universities. Notably, LACCEI's membership comprises a wide range of higher education institutions, professional organizations, and entities linked to engineering and technology across Latin America and the Caribbean. For this study, only active universities from Central America were considered, as detailed in Table 3.

As for the economic and legal agility indicators, they will be analyzed from a macroeconomic perspective of the ecosystem in which the universities operate. However, the analysis will focus specifically on the capacity of these institutions for the design and manufacture of microchips.

Table 3. Active members in Central America. Source:Own

ID	Country	Institution	Year of incorporation
1	Costa Rica	Universidad Fidélitas	2024
		Universidad Latina de Costa Rica	2023
2	Honduras	Universidad Nacional Autónoma de Honduras	2009
		Universidad Tecnológica Centroamericana	2003
3	Panamá	Universidad Tecnológica de Panamá	2008

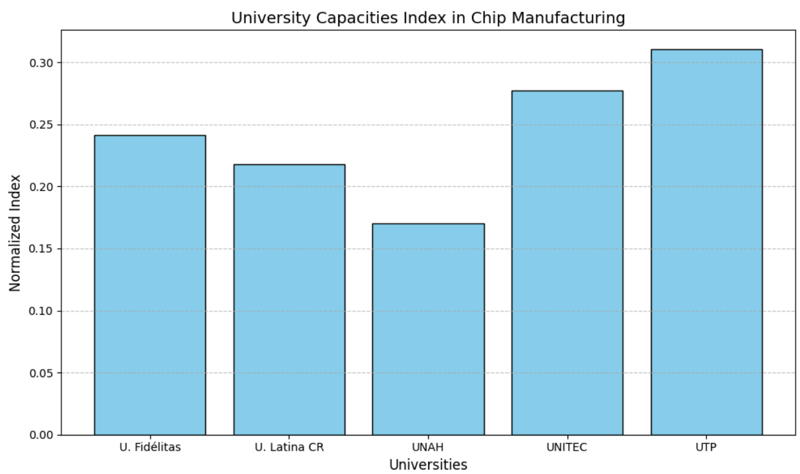

Figure 5. Index of university capacity in chip manufacturing.

Figure 5 shows the capacity index to develop a study process on chip manufacturing issues in the five universities. The index is valued between 0 and 1. The closer to 1 there is a greater opportunity in the process of accompanying the industrial and governmental sector for the creation of new goods or services in this sector. In the case of the Technological University of Panama, it is better positioned than the universities in the sample taken. However, a value of 0.3105 is a very low value for success in the training process in the subject of teaching on the subject of semiconductors.

It is important to mention that the indicators of scientific and technological production on the subject of chip manufacturing are null. These data were collected from the Scopus and Lens.org databases. Likewise, universities do not provide much information on their websites regarding the sub-indicators of human resources with scientific impact and the sub-indicator of technological infrastructure. You can see the values (raw and normalized) of the calculations performed in detail in Appendix IV.

Discussion

The capability index proposed in this study aims to assess the capacity of engineering universities to adapt, create, and transfer knowledge and technologies with the objective of fostering local and regional economic growth. The application of this model to the semiconductor and chip industry, particularly in Central America, demonstrates its potential to catalyze the transformation of engineering education, aligning university capabilities with the demands of strategic and advanced sectors. The adoption of this index will enable universities to assess their strengths and areas for improvement, facilitating a more strategic approach to the development of academic programs that integrate applied research, technology transfer, and industry collaboration. Furthermore, rapid changes beyond academic programs necessitate the reinvention of the educational approach.

A highlight of this study is its focus on the semiconductor and chip industry, a crucial sector for the development of advanced technologies and economic competitiveness of regions. The importance of semiconductors in today's global economy, particularly in areas such as computing, automotive, and telecommunications, underlines the urgent need to strengthen research and development capabilities in this field. Universities, as generators of knowledge and facilitators of technology transfer, play an essential role in the formation of highly qualified human capital capable of facing the challenges of this dynamic and highly complex sector.

At the regional level, especially in Latin America and the Caribbean, there is enormous potential to improve local capabilities in semiconductors and other advanced sectors by taking advantage of the knowledge and infrastructure that universities can offer [25]. However, this requires greater investment in research and development as well as close collaboration between universities, government, and industry. The proposed model also emphasizes the importance of legal agility and regulatory frameworks that facilitate the protection and commercialization of technological innovations, a barrier that persists in many regions.

This capability index not only seeks to measure the impact of universities but also serves as a strategic guide for policymakers, academic authorities, and industrial actors.Furthermore, this transformation process requires the identification of specific areas and technologies to concentrate the resources and efforts of applied research programs to maximize their impact. With this objective, in December 2024, LACCEI commissioned a Prospective Study of the Future of Engineering to identify emerging, converging, and transformative technologies.

In addition, LACCEI is working closely with the Organization of American States (OAS), as its Engineering Center of Excellence for the Americas, to support the OAS Prospecta America Initiative and its Centers of Excellence [26], created with a focus on transformative technologies, to connect research communities and support decision-making in the Americas region. Among the ten promising areas for the region identified are Artificial Intelligence (AI), Robotics, Big Data, Blockchain, Quantum Computing, Internet of Things, Virtual and Augmented Reality, 3D and 4D Printing, Biomedical Engineering, and Nanostructured Materials. Each center's mission is to identify and map future technological trends and developments that could have a direct economic or social impact on the livelihoods and development of communities in the Americas.

At the OAS Meeting of Ministers and High-Level Authorities on Science and Technology in December 2024 [27], ministers, high-level officials, and representatives from universities, research centers, civil society, and the private sector met to formulate a declaration and action plan to build consensus around policies, projects, and other solutions focused on governance, regulatory, and institutional frameworks for the safe, trustworthy, and ethical development of AI in the Americas.

Using the results of the commissioned foresight study, LACCEI identified its initial area of focus as semiconductor and chip materials, design, and manufacturing, considering it strategic for security and economy in the Americas. In 2022, the United States enacted the CHIPS and Science Act [22], with $280 billion in funding to support domestic research, manufacturing, and workforce development in this sector.

The CHIPS Act is divided as follows: the CHIPS (Creating Helpful Incentives to Produce Semiconductors) for America Act; the Research and Development, Competition, and Innovation Act; and the Supreme Court Security Funding Act. In 2024 commissioned studies, analysts estimated delays in funded projects due to bureaucracy and shortages of skilled workers, estimating that 40% of new workers are needed with two-year technical degrees and 60% with four-year engineering degrees or higher [28], [29][Conness, 2024] [Hayashi, 2024]. In March 2024, the Executive Office of the President of the United States released the National Strategy on Microelectronics Research [23], aligning private and public sectors in the national efforts to hasten and maximize results.

LACCEI conducted an analysis of what is needed for universities and countries to measure their capacity and identify and improve opportunities in an applied research area. Therefore, one of the results of that analysis was the development of the proposal developed in this paper.

Future Works

The capabilities index proposed in this study represents an initial step in measuring and evaluating engineering universities with respect to their capacity for adaptation, knowledge creation, and technology transfer. However, given that engineering education and technological capabilities development are dynamic processes, several areas warrant further exploration and expansion in future research:

- Expansion and validation of the index: It is recommended to expand and validate the index in different regional contexts and types of universities to test its effectiveness.
- Application of the index to other sectors: Although the study focuses on semiconductors, the index can be applied to other sectors, such as biotechnology, AI, renewable energy or more generally. This would allow us to see how universities impact economic development in different areas and key sectors.
- Development of monitoring tools: The index should evolve to become a dynamic tool that allows "real-time" monitoring of universities' capabilities.
- Integration of social and cultural factors: Consideration should be given to the inclusion of social and cultural factors.
- International collaboration and innovation networks: Strengthening international collaboration between universities, governments and industries will be crucial.
- Integration of a Capability Maturity Model (CMM): The integration of a Capability Maturity Model (CMM) to measure the evolution of universities (through levels) in their capacity to generate advanced technologies and compete globally is also recommended.
- Training: Develop a specific curriculum or roadmap for universities to advance or consolidate in the different levels of maturity of the model.
- Reliability of the Capability Index: To ensure the reliability of the index, a review by experts is necessary, along with the test of internal consistency using Cronbach's alpha. Additionally, pilot testing of the index should be conducted with a selected group of universities to evaluate the consistency of the results.

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Appendix I

Table 1. Indicators for measuring development capacity with their subcategories. Source: Own

Indicador	Concept
Economic Indicators	1.1. Research and development expenditure as a percentage of GDP. 1.2. STI policies in the country 1.3. Economic complexity of the product or service to be developed.
Legal Agility Indicators	2.1. Number of procedures to protect 2.2. Time for intellectual property protection
Scientific and Technological Production Indicators	3.1. Knowledge Creation Capacity 3.1.3. Number of research groups 3.2. Technology Transfer Capacity 3.3. Technological infrastructure
Human Resources Indicators with Scientific Impact	4.1. Number of engineering researchers 4.2. Mobility grants awarded to postgraduate students 4.3. Professors with PhD level 4.4. Professors linked to research networks 4.5. Doctoral Programs
Entrepreneurship Indicators	5.1. Number of Incubators 5.2. Number of University StartUps or Spin-Offs 5.3. Lifespan of the ventures 5.4. Open technological entrepreneurship programs in engineering and science faculties.

Appendix II

Indicators with their individual references

ID	Indicator	Concept	Ref.	Database
1	Indicadores Económicos	World Bank CEPAL BID		
1.1	Gasto en Investigación y desarrollo como un porcentaje del PIB.	Los gastos en investigación y desarrollo son gastos corrientes y de capital (público y privado) en trabajo creativo realizado sistemáticamente para incrementar los conocimientos, incluso los conocimientos sobre la humanidad, la cultura y la sociedad, y el uso de los conocimientos para nuevas aplicaciones. El área de investigación y desarrollo abarca la investigación básica, la investigación aplicada y el desarrollo experimental.	(1) (1a)	Unesco UIS Link
1.1.1	Exportaciones de alta tecnologías	Las exportaciones de alta tecnología son productos con una alta intensidad de investigación y desarrollo (I+D), tales como aeroespacial, computadoras, productos farmacéuticos, instrumentos científicos y maquinaria eléctrica. Los datos están en dólares estadounidenses corrientes.	(1.1.a) (1.1.b) (1.1.c)	World Bank WITS link
1.2	Políticas de CTI en el país	Las políticas son todas aquellos esfuerzos para estimular la CTI dentro de una región determinada, brindando de esta manera beneficios aquellos que hacen ciencia, tecnología e innovación.	1.2.a 1.2.b 1.2.c 4.1.b	Sitios webs gubernamentales
1.3	Complejidad económica del producto o servicio a desarrollar.	La complejidad económica mide la capacidad productiva de un país o región basada en el conocimiento necesario para producir bienes y servicios sofisticados. Se medirá la distancia, la oportunidad de ganancia y la ventaja Comparativa Revelada ¿Pueden las universidades producir tecnologías que eleven la complejidad económica del país o región?	(1.3a) (1.3b)	link
2.	Indicadores de Agilidad Jurídica	Propiedad intelectual Mixto: cualitativo y cuantitativo Pasos para una patente o propiedad Días.		
2.1	Cantidad de trámites para proteger		2.1, 2.2	
2.2	Tiempo de protección de propiedad intelectual		2.1, 2,2	
3	Indicadores de Producción Científica y Tecnológica	SCIMAGO		
3.1	Capacidad de Creación de conocimiento			
3.1.1	Cantidad de artículos científicos generados y su impacto en la comunidad científica.	Este indicador mide el **número total de artículos científicos publicados** por investigadores de una institución, país o región en un periodo de tiempo específico. Los artículos científicos son publicaciones revisadas por pares que presentan los resultados de investigaciones originales en revistas académicas. Este indicador es clave para evaluar la **producción científica** y la **contribución al conocimiento global** en diversas disciplinas.	3.1.1	
3.1.2	Cantidad de proyectos de Investigación ligados a una red de investigación.	Este indicador mide el **número de proyectos de investigación** que están asociados a **redes de investigación colaborativa**, ya sea a nivel nacional o internacional. Las redes de investigación son agrupaciones de instituciones o investigadores que colaboran para desarrollar	3.1.2	

		proyectos conjuntos, compartir recursos y conocimientos, y producir innovaciones colectivas. Este indicador refleja el **nivel de cooperación** y la **capacidad de trabajo interdisciplinario** en el ámbito científico, y puede ser un factor determinante para aumentar el impacto de los proyectos a través de la sinergia entre múltiples actores.		
3.1.3	Cantidad de grupos de investigación	Este indicador se refiere al **número de grupos de investigación** formalmente establecidos en una institución académica o de investigación. Un **grupo de investigación** es un equipo de científicos o académicos que trabajan juntos en torno a una línea de investigación específica, compartiendo recursos, conocimientos y objetivos comunes. La cantidad de grupos de investigación es un reflejo de la **estructura organizativa** y la **diversidad temática** en la producción científica de la institución.	3.1.2	
3.2	Capacidad de Transferencia Tecnológica	Patentes - WIPO Lens.org Espacenet - ESPAÑA		
3.2.1	Cantidad de Patentes	La **cantidad de patentes** se refiere al número total de solicitudes de patentes presentadas o concedidas en un país, institución, empresa o sector determinado durante un período de tiempo específico. Las patentes representan un derecho exclusivo otorgado por un gobierno a un inventor para explotar su invención durante un tiempo limitado, a cambio de la divulgación pública de los detalles de la invención	3.2.1 Powers (2003)	
3.2.2	Cantidad de diseños industriales	La **cantidad de diseños industriales** hace referencia al número de registros o solicitudes de protección de diseños industriales, que cubren los aspectos ornamentales o estéticos de un objeto. A diferencia de las patentes, los diseños industriales protegen la apariencia de un producto, pero no su funcionalidad. Este indicador mide la **creatividad en el diseño de productos** y la capacidad de una institución o empresa para proteger la apariencia visual de sus bienes, lo que puede impactar el valor comercial	Powers (2003)	
3.2.3	% de Patentes asignadas	El **porcentaje de patentes asignadas** se refiere a la proporción de patentes solicitadas que han sido efectivamente concedidas por una oficina de patentes en relación con el número total de solicitudes presentadas. Este indicador mide la **tasa de éxito** en el proceso de solicitud de patentes, lo que puede reflejar la calidad de las innovaciones propuestas, así como la solidez de los mecanismos legales y técnicos empleados para proteger las invenciones.	Powers (2003)	
3.2.4	Software Open/Close Sources	Este concepto mide la capacidad de las instituciones para **desarrollar y gestionar software** bajo modelos de desarrollo abiertos o cerrados, y cómo esos modelos impactan la transferencia de tecnología y su adopción por la industria.	3.2.4	
3.2.5	Cantidad de Oficina de Transferencia de Tecnología	Se refiere al número de oficinas dedicadas a facilitar la transferencia de tecnologías y conocimientos desde las universidades o centros de investigación hacia la industria o el mercado. Estas oficinas gestionan la comercialización de patentes, licencias, acuerdos de colaboración y startups.Este indicador mide la **capacidad de una institución** para **transformar el conocimiento académico en aplicaciones comerciales**, y su nivel de estructuración para facilitar la interacción con el sector productivo.	3.2.5b 3.2.5b	
3.2.6	Ingresos por patentes	Los **ingresos por patentes** son las ganancias obtenidas a través de la comercialización de patentes, ya sea mediante **licencias**, **royalties** (regalías) o la venta directa de los derechos de explotación de una patente. Este indicador mide la **rentabilidad de la actividad de innovación** y la **eficiencia en la transferencia de tecnología**, lo que puede reflejar el éxito en la conversión de ideas o invenciones en productos económicamente viables y valiosos para la industria.	Powers (2003)	
3.3	Infraestructura tecnológica	Propia universidad		

3.3.1	Laboratorio y Centros de Investigación	Son espacios equipados con instrumentos y tecnología especializada donde se realizan experimentos científicos, pruebas y estudios, con el fin de generar nuevo conocimiento o desarrollar tecnologías.	3.3a 3.3b	Sitio web Universidad
3.3.2	Equipamiento Avanzado	Se refiere a herramientas, maquinaria, instrumentos y tecnología de última generación que son esenciales para realizar investigaciones científicas y tecnológicas de alto nivel. Estos equipos permiten llevar a cabo experimentos y pruebas con **gran precisión y sofisticación**	3.3a 3.3b	Sitio Web Universidad
4	Indicadores de Recursos humanos de Impacto Científico			
4.1	Cantidad de investigadores por millón de personas	Este indicador mide el **número de investigadores** (científicos, académicos o tecnólogos dedicados a la investigación y desarrollo) por cada millón de habitantes en un país o región. Es un parámetro que refleja la **densidad de talento investigativo** en una población y está directamente relacionado con la capacidad de un país para generar conocimiento, innovar y desarrollar nuevas tecnologías. Un número más alto indica una mayor inversión en recursos humanos para la ciencia y la tecnología, lo que puede potenciar la competitividad y el desarrollo económico de la región.	4.1a 4.1b	Unesco UIS link
4.2	Beca de movilidad otorgadas a postgrados	Las **becas de movilidad** son apoyos financieros destinados a estudiantes de posgrado (maestría, doctorado o postdoctorado) para que realicen estudios o investigaciones en instituciones diferentes a su lugar de origen, ya sea a nivel nacional o internacional. Este indicador mide la cantidad de estudiantes de posgrado que reciben estas becas, lo que refleja las **oportunidades de intercambio académico** y la **circulación de talento**. Las becas de movilidad fortalecen la capacidad de un país o institución para acceder a **conocimiento global** y fomentar la colaboración científica internacional.	4.2a 4.2b	Sitio Web de Universidad
4.3	Profesores con nivel de PhD	La **proporción o número total de profesores que poseen un doctorado (PhD)** dentro de una universidad o institución educativa. El nivel de formación de los profesores es un factor clave que incide en la **calidad de la enseñanza** y la **capacidad investigativa** de una institución.	4.1b	Sitio Web Universidad
4.4	Profesores ligados a redes de investigación	Este concepto mide la cantidad de **profesores o investigadores que participan en redes de investigación colaborativa**, ya sea a nivel nacional o internacional. Las **redes de investigación** son agrupaciones de investigadores que colaboran en proyectos conjuntos, comparten recursos, conocimientos y resultados, y desarrollan innovaciones colectivas. Este indicador refleja el **grado de integración de los profesores en la comunidad científica global** y su capacidad para establecer colaboraciones que pueden aumentar el impacto de sus investigaciones.	4.1b	Sitio web universidad
4.5	Programas de Doctorado	Los **programas de doctorado** son estudios de posgrado avanzados que tienen como objetivo formar a investigadores y académicos altamente especializados en diversas áreas del conocimiento. Este indicador mide la **cantidad de programas de doctorado** ofrecidos por una institución, reflejando su capacidad para **generar investigadores de alto nivel** y fomentar la creación de nuevo conocimiento. Un mayor número de programas de doctorado suele estar asociado con una **mayor capacidad de investigación** y un entorno académico más rico y diverso.		WHED DataBases
5.	Indicadores de Emprendimiento	https://www.gemconsortium.org/data StartUp Genome		
5.1	Cantidad de Incubadoras	La **cantidad de incubadoras** se refiere al número total de **espacios de apoyo** destinados a fomentar el crecimiento de nuevas empresas (startups) mediante la provisión de recursos, asesoramiento y servicios. Las incubadoras suelen ofrecer infraestructura física, mentoría, acceso a	5.1a 5.1b	Sitio Web Universidad

		financiamiento y redes de contacto, además de programas de formación.		
5.2	Cantidad de StartUps o Spin-Off Universitarias	Este indicador mide el **número de startups o spin-offs** que han sido creadas a partir de la investigación o los proyectos desarrollados en instituciones educativas, especialmente universidades. Las **startups** son nuevas empresas que buscan implementar modelos de negocio innovadores, mientras que los **spin-offs** son empresas que se generan a partir de la transferencia de tecnología o conocimientos de una universidad o instituto de investigación. Un mayor número de estas iniciativas puede indicar un ambiente fértil para la **comercialización de la investigación** y la **generación de empleo**.	5.2a 5.2b	Sitio Web Universidad
5.3	Tiempo de vida de los emprendimientos	El **tiempo de vida de los emprendimientos** se refiere a la duración promedio que una startup o empresa mantiene su operación desde su fundación hasta su cierre, adquisición o consolidación en el mercado. Este indicador es fundamental para entender la **sostenibilidad** y la **viabilidad económica** de los emprendimientos en un ecosistema.		Sitio Web Universidad
5.4	Programa de emprendimiento tecnológico abiertos en las facultades de ingeniería y ciencias.	Este indicador mide la **existencia y alcance de programas formativos** dirigidos a fomentar el emprendimiento tecnológico en las facultades de ingeniería y ciencias de las universidades. Estos programas suelen incluir formación en creación de empresas, mentoría, acceso a financiamiento, talleres prácticos y apoyo para la elaboración de planes de negocio.		Sitio Web Universidad

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Appendix III

Weights of the indicators of the Capability Index. Source: Own

Indicator	Concept	Weight
Economic Indicators	1.1. Research and development expenditure as a percentage of GDP. 1.1.1. High-tech exports 1.2. STI policies in the country 1.3. Economic complexity of the product or service to be developed. 1.3.1. Distance 1.3.2 Gain Opportunity 1.3.3. Revealed comparative advantage	10%
Legal Agility Indicators	2.1. Number of procedures to protect 2.2. Time for intellectual property protection	10%
Scientific and Technological Production Indicators	3.1. Knowledge Creation Capacity 3.1.1. Number of scientific articles generated and their impact on the scientific community. 3.1.2. Number of research projects linked to a research network. 3.1.3. Number of research groups 3.2. Technology Transfer Capacity 3.2.1. Number of Patents 3.2.2. Number of industrial designs 3.2.3. % of Patents assigned 3.2.4. Open/Closed Source Software 3.2.5. Number of Technology Transfer Offices 3.2.6. Income from patents 3.3. Technological infrastructure 3.3.1. Laboratory and Research Centers 3.3.2. Advanced Equipment	35%
Human Resources Indicators with Scientific Impact	4.1. Number of engineering researchers 4.2. Mobility grants awarded to postgraduate students 4.3. Professors with PhD level 4.4. Professors linked to research networks 4.5. Doctoral Programs	25%
Entrepreneurship Indicators	5.1. Number of Incubators 5.2. Number of University StartUps or Spin-Offs 5.3. Lifespan of the ventures 5.4. Open technological entrepreneurship programs in engineering and science faculties.	20%

Appendix IV

Table for calculating the index using the sample of five universities as a sample.

ID	Indicador	Peso	Datos de cada indicador					Datos Normalizados				
			U.Fidelitas	U. Latina CR	UNAH	UNITEC	UTP	U.Fidelita_W	U_Latina CR_W	UNAH_W	UNITEC_W	UTP_W
	Indice base 0-1	**1**						**0,241**	**0,218**	**0,170**	**0,278**	**0,310**
	Indice base 0-100	**100**						24,146	21,806	17,024	27,760	31,046
1	**Indicadores Económicos**	**10**						7,929	7,929	2,029	2,029	4,042
1.1	Gasto en Investigación y desarrollo como un porcentaje del PIB.	3	0,28	0,28	0,06	0,06	0,18	3,000	3,000	0,000	0,000	1,636
1,2	Exportaciones de alta tecnologías como un porcentaje del total de exportaciones	1,5	1,50	1,50	0,01	0,01	0,04	1,500	1,500	0,000	0,000	0,030
1,3	Cantidad de Políticas de CTI en el país	1,5	7,00	7,00	3,00	3,00	4,00	1,500	1,500	0,000	0,000	0,375
1,5	Distancia	2	0,92	0,92	0,94	0,94	0,96	0,000	0,000	1,026	1,026	2,000
1,6	Oportunidad de Ganancia	1	0,98	0,98	1,05	1,05	0,05	0,929	0,929	1,000	1,000	0,000
1,7	Ventaja Comparativa Revelada	1	0,91	0,91	0,00	0,00	0,00	1,000	1,000	0,003	0,003	0,000
2.	**Indicadores de Agilidad Jurídica**	**10**						10,000	10,000	5,481	5,481	0,000
2.1	Cantidad de Pasos para proteger	4	6	6	7	7	7	4,000	4,000	0,000	0,000	0,000
2.2	Tiempo de protección de propiedad intelectual	6	40	40	149	149	1300	6,000	6,000	5,481	5,481	0,000
3	**Indicadores de Producción Científica y Tecnológica**	**35**						1,217	0,250	1,515	2,250	5,004
3.1	Capacidad de Creación de conocimiento	12						0,000	0,000	0,000	0,000	0,000
3,1,1	Cantidad de artículos científicos generados y su impacto en la comunidad científica.	5	0	0	0	0	0	0,000	0,000	0,000	0,000	0,000
3,1,2	Cantidad de proyectos de Investigación ligados a una red de investigación.	4	0	0	0	0	0	0,000	0,000	0,000	0,000	0,000
3,1,3	Cantidad de grupos de investigación	3	0	0	0	0	0	0,000	0,000	0,000	0,000	0,000

3.2	Capacidad de Transferencia Tecnológica	15						0,217	0,000	0,015	2,000	2,004
3,2,1	Cantidad de Patentes	4	0	0	0	0	0	0,000	0,000	0,000	0,000	0,000
3,2,2	Cantidad de diseños industriales	2	0	0	0	0	0	0,000	0,000	0,000	0,000	0,000
3,2,3	% de Patentes asignadas	2	0	0	0	0	0	0,000	0,000	0,000	0,000	0,000
3,2,4	Software Open/Close Sources	2	126	22	29	982	24	0,217	0,000	0,015	2,000	0,004
3,2,5	Cantidad de Oficina de Transferencia de Tecnología	2	0	0	0	0	1	0,000	0,000	0,000	0,000	2,000
3,2,6	Ingresos por patentes	3	0	0	0	0	0	0,000	0,000	0,000	0,000	0,000
3.3	Infraestructura tecnológica	8						1,000	0,250	1,500	0,250	3,000
3,3,1,1	Laboratorios	1	4	1	0	1	0	1,000	0,250	0,000	0,250	0,000
3,3,1,2	Centros de Investigación	3	0	0	1	0	2	0,000	0,000	1,500	0,000	3,000
3,3,2	Equipamiento Avanzado	4	0	0	0	0	0	0,000	0,000	0,000	0,000	0,000
4	**Indicadores de Recursos humanos de Impacto Científico**	**25**						0,000	3,627	8,000	8,000	12,000
4.1	Cantidad de investigadores en ingenieria	8	10	78	160	160	160	0,000	3,627	8,000	8,000	8,000
4.2	Beca de movilidad otorgadas a postgrados	4	0	0	0	0	0	0,000	0,000	0,000	0,000	0,000
4.3	Profesores con nivel de PhD	5	0	0	0	0	0	0,000	0,000	0,000	0,000	0,000
4.4	Profesores ligados a redes de investigación	4	0	0	0	0	0	0,000	0,000	0,000	0,000	0,000
4.5	Programas de Doctorado	4	0	0	0	0	5	0,000	0,000	0,000	0,000	4,000
5.	**Indicadores de Emprendimiento**	**20**						5,000	0,000	0,000	10,000	10,000
5.1	Cantidad de Incubadoras	5	0	0	0	1	1	0,000	0,000	0,000	5,000	5,000
5.2	Cantidad de StartUps o SpinOff Universitarias	6	0	0	0	0	0	0,000	0,000	0,000	0,000	0,000
5.3	Tiempo de vida de los emprendimientos	4	0	0	0	0	0	0,000	0,000	0,000	0,000	0,000
5.4	Programa de emprendimiento tecnológico abiertos en las facultades de ingeniería y ciencias.	5	1	0	0	1	1	5,000	0,000	0,000	5,000	5,000