7

NANOTECHNOLOGY AND ARTIFICIAL INTELLIGENCE: A PATENT REVIEW[1]

Ángeles Ortiz-Espinoza
angeles.ortiz.espinoza@uaz.edu.mx

Abstract

Nanotechnologies are the material basis of the disruptive technologies that comprise Industry 4.0. Their multipurpose and multifunctional characteristics have made possible their application in various areas, including artificial intelligence (AI), as they increase information processing capacity and connectivity between connection points: employing nanometric devices, it has been possible to generate intelligent software in ever smaller processors. The link between nanotechnologies and AI is an area of research that promotes the generation of broader technological developments with diverse applications. This paper aims to make an exploratory analysis of patents in nanotechnology with applications in AI that have been registered in recent years to distinguish regional trends and areas of application. For this purpose, a database was created based on the Patentscope of the World Intellectual Property Organization (WIPO). Among the main findings is the preponderance of Asian countries, particularly China, as leaders

1 This work is part of Conahcyt Science Frontier Research Project No. 304320: Critical description of nanotechnologies in Mexico

in the registration of nanotechnology and IA patents, as well as universities as the main agencies in the ownership of the registrations.

Keywords: *Nanotechnology, artificial intelligence, patent, industry 4.0, fourth industrial revolution*

Introduction

Nanotechnologies are the material basis of the disruptive technologies that make up the so-called Industry 4.0 (Foladori et al., 2017). Their multipurpose and multifunctional characteristics have made possible their application in various areas, including artificial intelligence (AI), as they increase information processing capacity and connectivity between connection points: employing nanometric devices, it has been possible to generate intelligent software in ever smaller processors. The link between nanotechnologies and AI is an area of research that promotes the generation of broader technological developments with diverse applications.

On the other hand, the most commonly used indicator to evaluate the level of innovation of nations is patents. The purpose of this paper is to examine innovation in Mexico and Latin America through the registration of nanotechnology-related patents. The choice to focus on nano patents is due to the fact that they constitute the essential material basis of current disruptive technologies, as well as those linked to connectivity and the development of the fourth industrial revolution, such as AI.

This paper aims to make an exploratory analysis of patents in nanotechnology with applications in AI that have been registered in recent years in order to distinguish regional trends and areas of application. This work is divided into four main parts. The first one talks about some important concepts that are AI and nanotechnology, and their relationship with patents; then we will expose the methodology used, to continue with the results obtained and finally point out some concluding remarks.

Important Concepts

Artificial Intelligence

Al is nothing more than the emulation of human intelligence through two main elements: on the one hand, we have computer systems that include both hardware and software to manage a combination of algorithms, which are the mathematical combinations that form the indications given to the machine or software to generate the desired result.

AI is a branch of computer science that focuses on developing systems capable of performing tasks that normally require human intelligence, i.e., it seeks to emulate human cognitive processes to create systems capable of performing tasks autonomously and efficiently (Ardila Osma et al., 2021; Torres-Solis & Quiroz-Juárez, 2023). These systems seek to replicate cognitive processes such as learning, perception, reasoning and decision making. To achieve this, AI employs various techniques and algorithms to process large amounts of data, identify patterns and make decisions based on that information. Some of these techniques include:

1) Machine learning: Develops computer systems that learn from data sets, eliminating the need for explicit programming by employing algorithms capable of autonomously finding solutions (Torres-Solis & Quiroz-Juárez, 2023).

2) Artificial neural networks: Are a simplified version of biological neurons and represent interconnected sets of artificial neurons arranged in layers (input, hidden and output) that transmit signals to each other (Torres-Solis & Quiroz-Juárez, 2023).

3) Natural language processing: Focuses on the interaction between computers and human language; its goal is to enable machines to understand, interpret and generate it effectively (Castillo Landínez et al., 2022; Torres-Solis & Quiroz-Juárez, 2023).

4) Computer vision: Enabling computers to understand and analyze images and videos so that they perceive them in a similar way to humans, which makes it possible to perform various tasks such as object

recognition, face detection, image segmentation, etc. (Rojas-Cuevas et al., 2022; Sánchez López, 2022)

Thus, AI focuses mainly on information processing and management, emulating human cognitive capabilities. However, in general, it does not involve material aspects, contrary to nanotechnology whose central axis is based on technical and material elements. According to what has been observed, it can be affirmed that for the current development of AI it has been crucial the creation of new devices of smaller size, greater processing capacity and data management, as well as a relatively low cost. This has been possible thanks to increasingly smaller structures, i.e., nanometer size. Nanotechnology has been fundamental in enabling access to and development of software capable of processing content intelligently.

Nanotechnology

The concept of nanotechnologies refers to the manipulation of matter at an extremely small scale, in the range of one to 100 nanometers (Comisión Europea, 2023). It should be noted that a nanometer is equivalent to one billionth of a meter (1 nm = 10^-9 meters), and at this scale, the properties of materials can vary significantly compared to the same material at a larger scale. In this sense, research in applied nanotechnology seeks to generate new products with innovative characteristics or improved properties for their productive application.

Nanotechnologies are considered to be of general super-purpose since they are based on the development of new physicochemical properties derived from the quantum forces manifested by materials at the nanometer scale (RS & RAE, 2004). Given that all production and service sectors make use of materials, nanotechnologies are rapidly being integrated into various industrial activities, services, and everyday life (Tsuzuki, 2009). These technologies are essential in the framework of the fourth industrial revolution since their material component enables the operation of key technologies of Industry 4.0, such as Big Data, IoT, Mobile Cloud Computing, Machine to Machine (M2M), fifth generation networks (5G), machine learning, among others (Oztemel & Gursev, 2020).

The current technological revolution is based on the implementation of smaller, more powerful, and economical sensors (Pérez, 2021), a trend that is expanding

with the advent of nano-sensors. The manipulation of the properties of matter at the nanometer level has made possible the creation of sensors with unprecedented data transmission and accumulation, thanks to the reduction in size and increase in processing power, fundamental aspects in current technological development (Schwab, 2017).

The connectivity and operation of the technologies associated with Industry 4.0, as well as the interconnection between them, depend to a large extent on Mems/Nems devices. The first link in the IoT value chain is related to the manufacturing of devices with specialized actuators and sensors for data capture (Castillo, 2017).

In this context, it is crucial to recognize the role of nanotechnologies in contributing to innovation in countries. However, innovation is intrinsically linked to the protection of these technologies, where patents play a fundamental role in determining not only who can use a particular technology, but also under what conditions it is applied.

According to the World Intellectual Property Organization (WIPO), a patent is an exclusive privilege granted to an invention, granting the holder control over its use and the ability to authorize to whom and in what manner it may be used (WIPO, 2023). The holders of the patent have the power to prevent its use or exploitation for profit by third parties, establishing that it cannot be used commercially without the consent of the holder (WIPO, 2023). With a term of 20 years from the date of disclosure, patents have a regional scope, since there is no universally valid patent, but their rights apply only in the countries or regions where the application for protection of the invention has been filed and approved, in accordance with local regulations (WIPO, 2023).

Historically, patents have been used as a means of safeguarding innovation, justified by the costs associated with the development of inventions with commercial and productive potential. The purpose is to provide the patent holder with a temporary period to recover the investment made in research. However, this practice also poses obstacles to innovation, as it limits access to emerging technologies that could serve as the basis for new innovations, despite the fact that the patent description is made public from the moment of application.

This structure of the patent system has been criticized in numerous investigations, pointing out dysfunctionalities both in terms of the rights they grant and their contribution to fostering innovation, together with the associated social costs, especially in developing countries (Dosi et al., 2023). The existence of patents implies the payment of licensing costs (Guzmán Ayala, 2023). Given that both incremental innovation and the creation of complex technologies or industries are based on previous innovations, considerable debate has been generated on how to reform the patent system, even considering its total abolition (Dosi et al., 2023).

This discussion takes on particular relevance in the field of nanotechnologies, as they serve as the material basis for generating other types of innovations. Therefore, restricting their use could limit the generation and application of disruptive technologies, as well as technology transfer between countries, regions and even sectors.

Methodology

The methodology employed consisted of three parts: in the first part, the database was generated from information compiled in the Patenscope of the World Intellectual Property Organization. Subsequently, a descriptive analysis was made with this information. Next, a simple data mining analysis was carried out using open access software. The time period covered was from 1993, date of the first record found, to August 2023.

For the generation of the database, initially the information on the cover page was taken into account, at first it was requested that the patent records include the term "artificial intelligence", as well as the International Patent Classification (IPC) codes B82, B82B and B82Y, related to nanotechnology. This request generated 41 observations. A second request was made for the cover page to include the terms "nano" and "artificial intelligence" without specifying codes, which generated 118 records. However, four duplicates were identified between the first and second procedure, as well as five records that were irrelevant, since the term "nano" referred to aspects unrelated to nanotechnology, as they were linked to trademarks or names of the applicants.

Table 1. IPC Codes on Nanotechnology

IPC Codes	Description
B82	Nanotechnology using the terms *nanosize* or *nanoscale* relate to a controlled geometrical size below 100 nm in one or more dimensions, and *nanostructure* means an entity having at least one nanosized functional component that has properties or effects available, which are uniquely attributable to the nanoscale (WIPO, 2023).
B82B	Refers to nanostructures formed by the manipulation of atoms or molecules individually or in limited or discrete collections, as well as to their manufacture or treatment (WIPO, 2023).
B82Y	Specific uses or applications of nanostructures; their measurement, analysis, manufacture or treatment. It covers applications and aspects of nanostructures that are produced by any method, and is not limited to those formed by manipulation of atoms or molecules (WIPO, 2023).

Source: Own elaboration based on WIPO, 2022

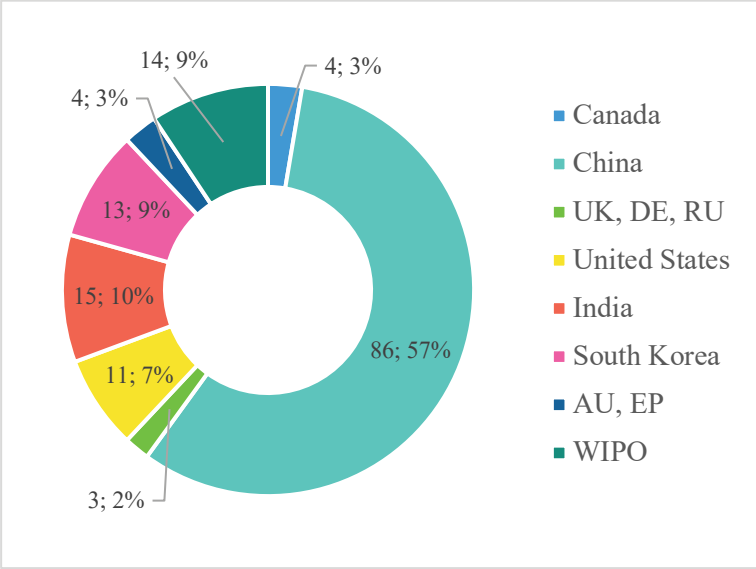
With the database obtained, a descriptive statistical analysis of nanotechnology patents with applications for AI was carried out. Then, the information from the abstracts of the records was used to perform a data mining analysis to determine the most frequent codes or areas of application in the patent applications, as well as to identify the relationship between them, especially in the most common IPC codes.

Results

In relation to the descriptive analysis, highly revealing results were obtained. Firstly, China stands out as the main generator of patents in nanotechnology and AI with just over half of the registrations (57%), followed by international patent offices, which contribute with approximately 10% of the registrations collected. The choice of registering in a specific office responds to commercial and economic interests. It is fundamental to note that there is no international or global patent per se. Still, it is possible to register and apply for patents in some offices comprising several countries or regions, for example, the European Patent Office validates the registration in each country belonging to the European Union, as well as in regional offices in Africa or Latin America.

A more in-depth review of the contribution of the international patent office in the first process for generating the database, i.e., the one that includes the term "artificial intelligence" and the codes related to nanotechnology, shows that Japan and South Korea are the countries with the highest number of registrations. On the other hand, when evaluating the records obtained from the combination of the terms "artificial intelligence" and "nano" in the cover information, it is the United States that leads in the number of records, together with the 7% that are registered directly in the U.S. office.

Figure 1. Patents´ Distribution by Registration Office



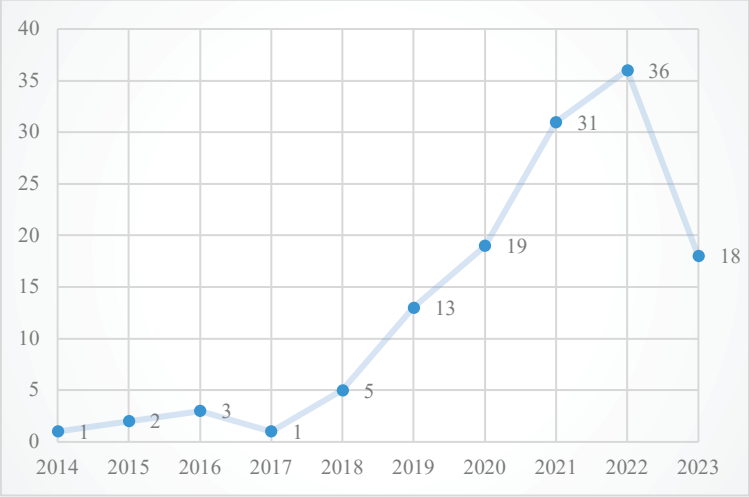
Source: Own elaboration based on WIPO, 2022

In terms of annual registration trends, we see that the first patent registration involving nanotechnology and AI dates back to 1993. This initial registration corresponds to an application for the generation of quantum computers in Germany. This finding supports the idea that the disruptive technologies used in Industry 4.0 are not novel, but the current material capability, largely driven by

nano, has significantly encouraged the use of some technologies that had not reached their potential.

One notable finding is that, between 1993 and 2003, only two registers that link "nano" and "artificial intelligence" patents were filed. However, during the following decade (2004-2013), an increase to 19 registrations is observed, with the second half of the 2000s being the period with the highest number of entries, reaching a peak in 2022 with 36 registered patents. Although a decrease in the number of entries is perceived in 2023, this could be attributed to the timing of the completion of the monitoring of these patents, which was in the middle of the year in question.

Figure 2. Patents´ Distribution by Year



Source: Own elaboration based on OMPI, 2022

Regarding the type of agency filing patents, the participation of China stands out, where the leading entities in applications related to AI and nanotechnology are mainly universities, closely followed by companies and collaborations. Due to their wide participation in China, universities are the main applicants, representing 37.3% of the total number of registered patents. However,

individual-level registrations and those made through companies also play an important role contributing 31.3% and 22.0% of total patent applications respectively.

In filing collaborative patent applications, China stands out compared to other countries or offices, since of the 14 registrations found involving more than one agency, 11 are in China, representing 9.3% of the total. Although there are only collaborations in three of the offices that register patents in the area (China, USA and the international office), the importance of collaboration between different actors and the relevance of the so-called "triple helix" to carry out research with practical applications is noteworthy, since the country that patents the most is the one that has the highest number of collaborations and patents from academia.

Along the same lines, it should be noted that around 37.3% of the collaborations are linked to universities. Although most of these are produced in the leading country in patents related to nano and AI, it is worth noting that this percentage offers a perspective on the importance of research from academia, even more so if it has an outlet to the market and the productive sectors. As will be seen below, the main area of application between nano and AI is the medical and financial sectors, sectors that are known to be quite profitable.

Table 2. Distribution by Type of Applicants

	Collaborations	Companies	Individuals	Universities	Overall Total
Autralia			1	1	2
Canada			4		4
China	11	19	10	46	86
Germany			1		1
European Office		2			2
United Kingdom			1		1
India			12	3	15
South Korea		2	10	1	13
Russia			1		1
USA	2	3	4	2	11
International Office	1	7	3	3	14
Overall Total	14	33	47	56	150
Porcentage	9.3	22.0	31.3	37.3	100.0

Source: Own elaboration based on WIPO, 2022

In general terms, the main records focus on three main areas: Physics, medical purposes, and uses, analysis, or manufacture of nano-structures:

- Physics (IPC CODE G):
    - Computing arrangements based on specific computational models 2 : IPC Code G06N. This class covers biological models, knowledge-based models, specific mathematical models, quantum computing, and machine learning (WIPO, 2023).
    - Learning methods: IPC CODE G06N 3/08. Refers to constructed from tangible entities governed by simulated intelligence to imitate intelligent life forms, such as employing robots that emulate the appearance or behavior of pets or humans (WIPO, 2023).
    - Health informatics: IPC CODE G16H. Information and Communication Technology [ICT] specifically designed for the management or processing of medical or healthcare information (WIPO, 2023).
- Uses, analysis, or manufacture of nano-structures (IPC CODE B82Y):
    - Nanotechnology for the processing, storage or transmission of information: IPC Code B82Y 10/00. Some examples are quantum computing, single-electron logic (WIPO, 2023), or magnetic materials (Prasad et al., 2018).

2 Although the information available in the online IPC code base does not provide a detailed definition of this item, considering that 1) computing arrangements refers to the structuring of elements in informatics and computing; 2) specific computational models are theoretical or conceptual abstractions that describe the operation of a computational process, and 3) the type of patents registered under this item, it can be inferred that this code is linked to the structuring of data, algorithms and other physical or logical components for the resolution of a specific problem.

  - Manufacture or treatment of nanostructures: IPC CODE B82Y 40/00. refers to the process of producing nanostructures for different purposes (WIPO, 2023).

- Medical purposes (IPC CODE A61):

  - Preparations for medical, dental or toiletry purposes. IPC Code A61K. includes devices or methods adapted to give pharmaceutical products particular physical or administration forms, as well as chemical aspects or use of materials for deodorization, disinfection or sterilization, as well as for bandages, dressings, absorbent compresses or surgical articles or soap structures (WIPO, 2023).

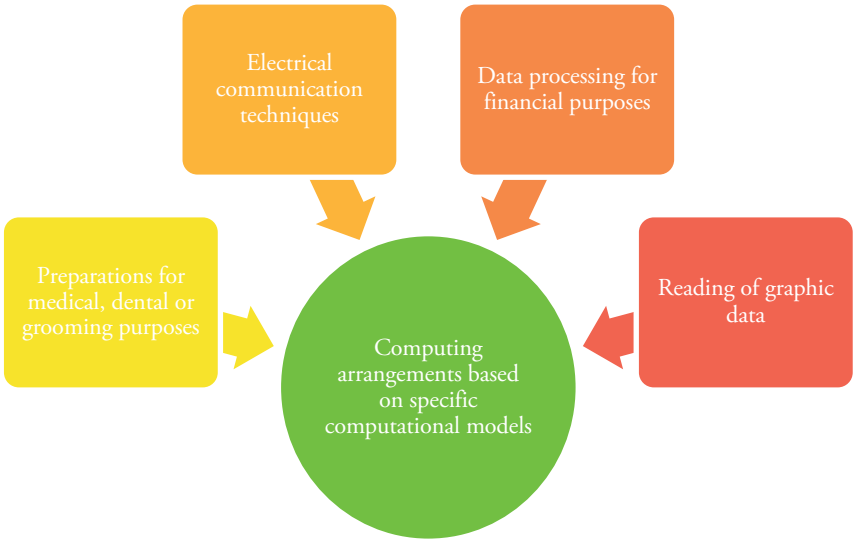
  - Diagnosis; surgery; identification: IPC Code A61B. Encompasses tools, devices, and techniques utilized in diagnostic, surgical, and personal identification applications (WIPO, 2023). This includes items for obstetrics, tools for corn removal, vaccination equipment, fingerprinting tools, and psycho-physical tests (WIPO, 2023).

It highlights the growing relevance of nanotechnology in medical, dental and health applications, possibly influenced by the recent COVID-19 crisis. It is also notable that three of the top areas of registration are linked to information processing, while the health sector is the only one identified as a specific application sector. This is evidence of a greater association of nanotechnology and AI with data generation and production than with a specific use in a particular area or social matter.

Along the same lines, the data mining analysis performed to identify key relationships among the IPC codes highlighted several significant associations. The computational arrangements, for example, exhibit a strong correlation with medical training, records linked to healthcare use and technical innovations in communication. In addition, the connection with data processing for financial purposes is highlighted, encompassing thematic areas related to banking, international trade, among others. In this context, cybersecurity emerges as a factor of great relevance, especially in data protection. Another recurring

application closely linked to computational arrays is the reading of graphic data, which involves the processing of images and audiovisual content.

Figure 3. Main IPC Codes and Related Areas

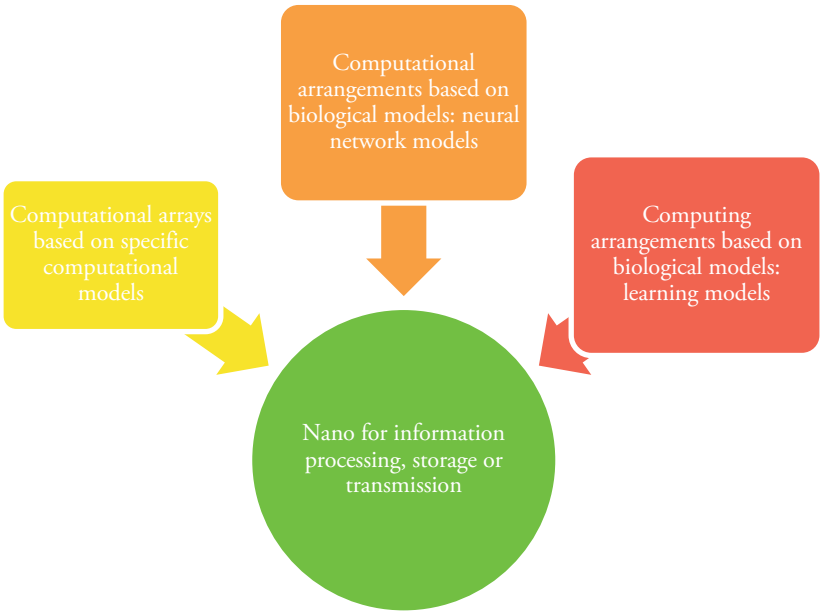


Source: Own elaboration based on WIPO, 2022

As for the second most recurrent code, which refers to the use of nanotechnology for information processing, a strong connection with computational arrays based on biological models is evident. This is linked to the very definition of AI in terms of emulation of human intelligence. In this context, it is confirmed that this area is a research priority, since the three associated codes refer to computational arrays, i.e. computational structures that seek the solution of a specific problem. However, the first one deals with computational arrays in general, while the other two specify biological models in which both neural networks and deep and machine learning models are considered.

Thus, according to the correlations obtained between the links of the IPC codes used between nanotechnology and AI, it is reiterated that more and more precise ways of emulating human capacitance for decision making and information systematization are being sought.

Figure 4. Second Main IPC Codes and Related Areas



Source: Own elaboration based on WIPO, 2022

Concluding remarks

This study offers an in-depth examination of the convergence of nanotechnologies and AI by focusing on patent registrations. The research explores the pivotal role of patents as key indicators of innovation, especially in the realm of transformative technologies like nanotechnology and AI. The primary aim of this investigation was to conduct an exploratory analysis of patents in nanotechnology associated with applications in AI, which have been

registered in recent years, in order to discern regional trends and specific application areas.

It is essential to highlight some key findings. The analysis underscores the significant influence of Asian countries, particularly China, in driving research and innovation in the field of nanotechnology and AI. From the perspective of patents, China stands out as the main producer of this type of technology and is among the main countries that promote collaboration between various agents to generate and drive innovation. This same country stands out in terms of the importance of collaboration between actors, as the triple helix has become an essential component for putting research into practice.

Moreover, the document sheds light on the growth in the number of patents linking medicine and healthcare, emerging as the primary area of application for nanotechnology an AI; this trend underscores the pivotal role this item in advancing healthcare technologies. In this sense, it is important to point out that it is one of the few specific areas that stands out, since patent research has been seen to be more related to forms and methods of data capture or specific processes for solving computational problems, than to application sectors. This is the case of the growing importance of nanotechnology with a focus on biological arrays, seeking to develop nano components that emulate more and more precisely the behavior and learning processes of the human mind.

The data point to low collaboration between the different actors, but highlight that such collaboration is most prevalent in China, the country with the highest number of nanotechnology and AI registrations. The importance of collaboration between actors has always been emphasized, highlighting the triple helix model as an essential component in translating research into practical applications. This underscores the importance of fostering synergistic partnerships between academia, industry and government to drive innovation and technological breakthroughs in the field of nanotechnology and AI. In this regard, he highlights the role of universities, which have the largest number of patent registrations, underlining the need to bring this research to the public, either through governments or private companies.

Although the work presented is mostly descriptive, it provides valuable insights into the main trends in patent filings that link these two crucial areas for the

development and implementation of the disruptive technologies of the so-called Industry 4.0 and the fourth industrial revolution. Although the analysis is concise, it provides clues about the research directions, the sectors of interest, the actors involved and the global distribution of nanotechnologies linked to AI. A more in-depth and analytical investigation will be reserved for future studies.

References

Ardila Osma, J. A., Salcedo Gonzalez, E. F., Pedraza Aguirre, C. A., & Saavedra, M. (2021). Revisión sobre hacking ético y su relación con la inteligencia artificial. *Reto*, *8*(1), 11–21. https://doi.org/10.23850/reto.v8i1.3064

Castillo Landínez, S., Caicedo Rodríguez, P. E., & Mosquera Bolaños, J. A. (2022). *Los adolescentes y el uso de las redes sociales. Un análisis desde la óptica de la ciencia de datos y el procesamiento de lenguaje natural*. 1–8. https://doi.org/10.26507/paper.2693

Castillo, M. (2017). *La Internet industrial para el cambio estructural en América Latina*. Institut Barcelona d'Estudis Internacionals (IBEI). https://www.jstor.org/stable/resrep14197

Comisión Europea. (2023, mayo 2). *Nanomaterials: Guiding EU industries into the huge potential of the infinitesimal world*. https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/nanomaterials-guiding-eu-industries-huge-potential-infinitesimal-world-2023-05-02_en

Dosi, G., Palagi, E., Roventini, A., & Russo, E. (2023). Do patents really foster innovation in the pharmaceutical sector? Results from an evolutionary, agent-based model. *Journal of Economic Behavior & Organization*, *212*, 564–589. https://doi.org/10.1016/j.jebo.2023.05.039

Foladori, G., Figueroa, E. A., Lau, E. Z., Appelbaum, R., Robles-Belmont, E., Vázquez, L. L. V., Parker, R., & Leos, V. (2017). La política pública de nanotecnología en México. *Revista Iberoamericana de Ciencia, Tecnología y Sociedad - CTS*, *12*(34), 51–64.

Guzmán Ayala, E. (2023). *¿Las Patentes Incentivan o Desincentivan la Innovación?* https://www.iseade.edu.sv/index.php/cpc/articulos/innovacion-y-tecnologia/101-las-patentes-incentivan-o-desincentivan-la-innovacion

Oztemel, E., & Gursev, S. (2020). Literature review of Industry 4.0 and related technologies. *Journal of Intelligent Manufacturing*, *31*(1), 127–182. https://doi.org/10.1007/s10845-018-1433-8

Pérez, E. (2021, marzo 28). *Los transistores más pequeños jamás creados: Estas son las soluciones para miniaturizar la electrónica más allá de los 2 nanómetros*. Xataka. https://www.xataka.com/componentes/transistores-pequenos-jamas-creados-estas-soluciones-para-miniaturizar-electronica-alla-2-nanometros

Prasad, P. D., Prasada Reddy, P. S., Assefa, A. G., Rao, V. T., & Rao, G. N. (2018). Synthesis and Photocatalytic Studies of Fe3O4 Nanoparticles. *Journal of Nanoscience and Technology*, *4*(4), 443–446. https://doi.org/10.30799/jnst.135.18040411

Rojas-Cuevas, I. D., Méndez-López, L. G., Mendoza-Vázquez, J.-R., Ramírez-Palacios, V., & Torres Méndez, S. J. (2022). Sistema multiplataforma de gestión de datos para visión por computadora. *Programación Matemática y Software*, *14*(2). https://doi.org/10.30973/progmat/2022.14.2/7

RS, & RAE. (2004). *Nanoscience and nanotechnologies: Opportunities and uncertainties*. https://royalsociety.org/~/media/royal_society_content/policy/publications/2004/9693.pdf

Sánchez López, L. A. (2022). Inteligencia artificial y visión por computadora aplicada a la educación. *REVISTA ODIGOS*, *3*(2), 61–73. https://doi.org/10.35290/ro.v3n2.2022.587

Schwab, K. (2017). *La cuarta revolución industrial*. Debate.

Torres-Solis, C. A., & Quiroz-Juárez, M. A. (2023). Convergencia de la inteligencia artificial y la nanotecnología. *Mundo Nano. Revista Interdisciplinaria en Nanociencias y Nanotecnología*, *16*(31), Article 31. https://doi.org/10.22201/ceiich.24485691e.2023.31.69775

Tsuzuki, T. (2009). Commercial scale production of inorganic nanoparticles. *International Journal of Nanotechnology*, *6*, 567–578. https://doi.org/10.1504/IJNT.2009.024647

WIPO. (2022). *Patentscope* [dataset]. https://patentscope.wipo.int/