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A multidimensional approach to Mexican scientific output from 2010-2019

Uma abordagem multidimensional da produção científica mexicana de 2010-2019

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Abstract

The current work aims to characterize the Mexican scientific production in 22 main fields and 151 thematic subfields, using a multidimensional methodology based on productivity, impact and Altmetric measures. Data were extracted from Dimensions database. Indicators available at Dimensions Analytics service were used and represented via LabSOM software and ViBlioSOM methodology, based on artificial neural networks. The characteristics of the major fields and their corresponding subfields were studied. Multidimensional maps based on the Kohonen algorithm were constructed. Activity index, attractivity index, relative impact, field citation ratio, percentage of publications with Altmetric Attention, and Altmetric Attention Score were the indicators chosen for visual representation. Mexican scientific production experimented an exponential growth during the period 2010-2019. Agricultural and Veterinary Sciences, Environmental Sciences, Physical Sciences, Biological Sciences, Earth Sciences, Mathematical Sciences and, surprisingly, History and Archeology achieved the best bibliometric performances in relation to the world. The artificial intelligence-based method allowed the analysis of specific characteristics of Mexican scientific activities and common links among research practices in different knowledge domains.

Keywords: Mexico. Multidimensional analysis. Science mapping. Scientific output. Self-organized maps.

Resumo

O presente trabalho visa caracterizar a produção científica mexicana em 22 categorias temáticas e 151 subcampos temáticos, utilizando uma metodologia multidimensional baseada em produtividade, impacto e métricas alternativas. Os dados foram extraídos do banco de dados Dimensions. Os indicadores disponíveis no serviço Dimensions Analytics foram utilizados e representados por meio do software LabSOM e da metodologia ViBlioSOM, baseada em redes *neurais artificiais. Foram estudadas as características dos principais campos temáticos e subcampos. Mapas multidimensionais baseados no algoritmo de Kohonen foram construídos. Para a representação visual, foram escolhidos o índice de atividade, índice de atração, impacto relativo, razão de citação por campo, percentual de publicações com atenção altmétrica e nota de atenção altmétrica. A produção científica mexicana cresceu exponencialmente durante o período 2010-2019. Ciências Agrárias e Veterinárias, Ciências Ambientais, Ciências Físicas, Ciências Biológicas, Ciências da Terra, Ciências Matemáticas e, surpreendentemente, História e Arqueologia obtiveram os melhores desempenhos bibliométricos em relação ao mundo. O método baseado em inteligência artificial permitiu analisar características específicas das atividades científicas mexicanas, bem como os vínculos comuns entre as práticas de pesquisa desenvolvidas em vários domínios do conhecimento.*

Palavras-chave: *México. Análise multidimensional. Mapeamento Científico. Produção científica. Mapas auto-organizados.*

Introduction

Mexican science has frequently been studied from a bibliometric approach. There are quite studies on the Latin American region in which some characteristics of the scientometric performance of Mexico have been analyzed (Alcazar Farias; Lozano Guzman, 2009; Chinchilla-Rodriguez *et al.*, 2015; Collazo-Reyes; Luna-Morales; Luna-Morales, 2017; Collazo-Reyes *et al.*, 2008; Macias-Chapula, 2013). Other papers were focused on the evolution of the Mexican scientific output in specific fields, such as Physics, Astronomy, Psychology, or Health Sciences (Arvanitis; Russell; Rosas, 1996; Collazo-Reyes; Luna-Morales; Russell, 2004; del Río; Russell; Juárez, 2020; Montero y López Lena, 1997; Luna Morales; Luna Morales; Sanchez Martinez, 2013).

A varied repertoire of bibliometric techniques and indicators has been used in these studies (Bravo Vinaja, 2005; Castillo-Pérez; Muñoz-Valera, 2014; de Arenas; Castanos-Lomnitz; Arenas-Licea, 2002; Gantman; Fernandez Rodriguez, 2017; Aleixandre *et al.*, 2016; Perez-Santos; Anaya-Ruiz, 2013; Sierra-Flores *et al.*, 2009). Some papers taking advantage of the capabilities of the artificial neural network (ANN) have been identified (Guzmán Sánchez; Sotolongo Aguilar, 1998; Sotolongo Aguilar; Guzmán Sánchez; Carrillo, 2002; Villaseñor; Arencibia-Jorge; Carrillo-Calvet, 2017). Web of Science (Clarivate Analytics) and Scopus (Elsevier) are the main bibliographic databases used by the vast majority of these studies. Specialized data sources such as PubMed, or national databases such as REDALYC, *Clase and Periódica* have also been covered by some authors. Productivity, impact and collaboration have been the most studied variables.

However, none of the previously cited papers have exploited the potential advantages of Altmetric indicators, and only one poster presentation combines bibliometric and Altmetric indices to analyze Mexico at the macro level using Dimensions (Arencibia-Jorge *et al.*, 2021). This new multidisciplinary bibliographic database was recently launched on the market, and it has proven to be very useful for scientometric analysis (Gontijo; Hamanaka; de Araujo, 2021).

In this paper, ANN and self-organizing maps (SOM) are applied to create a scientometric profile, combining productivity, impact and Altmetric measures to obtain a multidimensional representation of the Mexican scientific domain. The main aim is to characterize the Mexican scientific production in 22 major fields and 151 subfields covered by Dimensions.

Materials and Methods

Datasets, search strategy and procedure

Dimensions, a database developed by Digital Science & Research Solutions (United Kingdom), was used to build the Mexican thematic multidimensional profile. Launched in 2018, Dimensions contains more than 113 million scholarly papers, 54 million patents, 5,6 million grants, 1,5 million datasets, 590 thousand clinical trials and 550 policy documents, making this source one of the most comprehensive tools to analyze scientific production around the world. Web of Science Core Collection (WoS Core) and Scopus were also used for comparative purposes.

Thanks to the free data access program for scientometrics researchers developed by Digital Science, all the Mexican scholarly documents with a Digital Object Identifier (DOI) during the period 2010-2019 were identified. Mexico was selected using the field "Location-Research Organization" of database. The field "Publication year" was used to refine the period.

Using the Dimensions Analytics interface, the field "Research categories" was analyzed. In this field, the scientific output is structured in a major classification scheme, based on the Australian and New Zealand Standard Research Classification (ANZSRC). The classification categories include 22 major fields and related sub-fields of research and emerging areas. A battery of academic impact indicators and Altmetric Attention for each category were obtained.

Tables in XLSX (Microsoft Excel) format with primary Dimensions indicators were downloaded. Data were retrieved on October 8th, 2020. Primary indicators were relativized to compare Mexico with the world general performance by each research category. The new table with relative indicators for each category was processed using a neural network technique, to obtain a multidimensional scientometric map that represents the thematic characteristics of Mexican scientific production.

Indicators

The following primary indicators, developed by Digital Science & Research Solutions (2018), were obtained:

• ***Publications (Npub)***: number of publications related to the search. In this case, worldwide and Mexican publications by year and by each research category during the period were obtained.

• ***Citations (Ncit)***: number of times that other publications in the database have cited a publication. Citing publications can be of any publication type, such as articles, chapters, preprints, or monographs. In this case, worldwide and Mexican citations by each research category during the period were obtained.

• ***Citations mean (Ncit mean)***: mean citations per publication.

• ***Field citation ratio (FCR)***: relative citation performance of a publication compared to similarly-aged articles in its subject area. FCR is calculated for all publications in Dimensions, which are at least 2 years. In this case, the geometric mean FCR by each research category was obtained, reducing the effect of outlier publications with excessive citation rates. A value of more than 1.0-1.5 indicates higher than mean citation (Digital Science & Research Solutions, 2018).

• ***Publications with attention (Pub Att)***: number of publications with Altmetric Attention. This includes mentions in public policy documents and references in Wikipedia, mainstream news, social networks, blogs and more, according to the Altmetric, a web service platform also developed by Digital Science & Research Solutions. In this case, the percentage of worldwide and Mexican Pub Att by year and by each research category during the period was obtained (Digital Science & Research Solutions, 2018).

• ***Altmetric Attention Score (AAS)***: it is a weighted count of all of the online Altmetric Attention has found for an individual research output. In this case, the worldwide and Mexican

AAS mean by year and by each research category during the period was obtained (Digital Science & Research Solutions, 2018).

Based on primary indicators, the following battery of relative indicators was developed:

• ***Activity index (AI)***: based on the countries' AI (Frame, 1977), this index is calculated to identify the level of thematic specialization of each research category through the following procedure:

AI = (Npub $_{\text{Mexico (category)}}$ / Npub $_{\text{Mexico (total)}}$) / (Npub $_{\text{World (category)}}$ / Npub $_{\text{World (total)}}$)

• ***Attractivity index (Attract)***: Based on the countries' Attract (Braun; Schubert, 1997), it is calculated to determine the visibility of companies through the following procedure:

Attract = (Ncit $_{\text{Mexico (category)}}$ / Ncit $_{\text{Mexico (total)}}$) / (Ncit $_{\text{World (category)}}$ / Ncit $_{\text{World (total)}}$)

• ***Relative impact (RI)***: based on mean citations per publication, this index is calculated to identify the RI of Mexico with respect to the world in each research category.

RI = Ncit $_{\text{mean Mexico (category)}}$ / Ncit $_{\text{mean World (category)}}$

For the rest of the indicators, the same principle was followed to compare Mexico's behavior in each research category with respect to the world.

Relative FCR = FCR $_{\text{Mexico (category)}}$ / FCR $_{\text{World (category)}}$

Relative Pub Att = % Pub Att $_{\text{Mexico (category)}}$ / % Pub Att $_{\text{World (category)}}$

Relative AAS = AAS $_{\text{Mexico (category)}}$ / AAS $_{\text{World (category)}}$

In all cases, values higher than 1 express a higher performance with respect to the world. To facilitate representation, a scale of values between -1 and 1 was used (Glänzel, 2000). The 0 value is the position of the world in each research category.

Artificial intelligence method

An artificial intelligence method was developed to automatically carry out the multidimensional characterization of 22 main fields and 151 subfields, in which Mexican scientific output is distributed. The data mining procedure is based on the SOM family of neural networks (Kohonen, 2013). The method was previously applied in Mexico's scientometric studies (Arencibia-Jorge *et al.*, 2021; Villaseñor; Arencibia-Jorge; Carrillo-Calvet, 2017), which is graphically described in Figure 1.

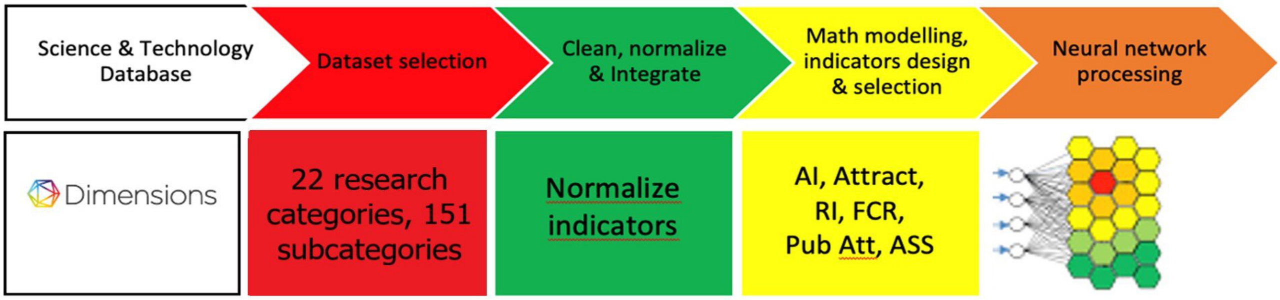


Figure 1– Methodology for data clustering and visualization using self-organizing maps neural networks
Source: The authors (2021).

The method was implemented in a software system called LabSOM, developed by the Laboratory of Nonlinear Dynamics at the Faculty of Sciences of the National Autonomous University of Mexico (UNAM) and the company *Tecnologías Inteligentes y Modelación de Sistemas* (TIMS). With this tool, the multidimensional data analysis and interpretation are automated and facilitated through friendly visualization.

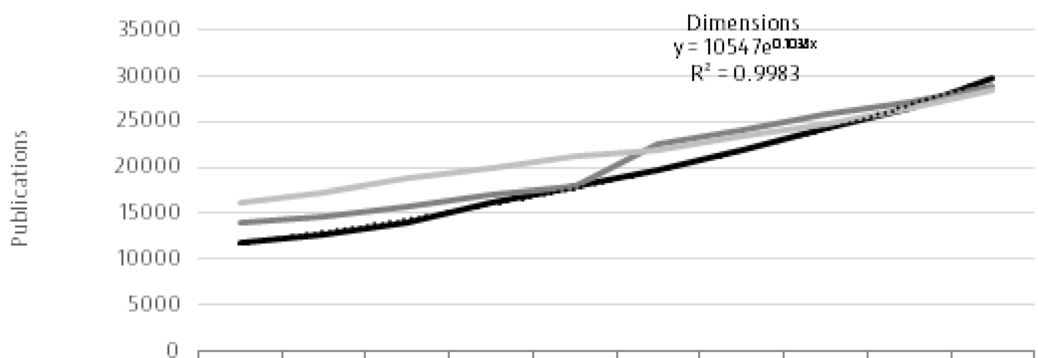
The SOM neural network was modeled as a two-dimensional hexagonal grid. Each hexagon represents an artificial neuron and, at the same time, a location where data points can be mapped. A nonlinear projection of data into the neural network was developed. During the neural network iterative training, the network learns to project similar patterns into close locations (hexagons) in a 2D map. Similarities between research area performances can be estimated by calculating the ''scientometric distance'' among their multidimensional representations (Villaseñor; Arencibia-Jorge; Carrillo-Calvet, 2017).

Finally, a discussion about the Mexican scientific production and the communication channels to strengthen ties between scientists and society was proposed.

Results

Mexican scientific production covered by Dimensions during the period 2010-2019 reached 195,015 documents on October 8th, 2020, and it has shown an exponential growth trend (R^2=0.9983) (Figure 2).

The evolution of the database coverage is clear when it is compared to the two main bibliographic databases: WoS Core and Scopus. Scopus starts the period with the highest coverage of Mexican scientific literature. However, a clear jump was observed since 2015, when Emerging Sources Citation Index was included in the WoS Core. At the end of the period, Dimensions exceeded Scopus (since 2018) and WoS Core (2019), proving its weight as a contender in the bibliographic database market (Figure 2).



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Dimensions	11870	12686	14036	16286	18027	19767	21931	24200	26526	29686
WoS Core	14029	14631	15685	17075	17865	22548	24175	25820	27196	28942
Scopus	16275	17334	18748	19900	21334	21815	23336	24817	26426	28490

Figure 2 – Evolution of the Mexican scientific production during the period 2010-2019.
Sources: The authors, based on Dimensions data; Digital Science and Research Solutions (2021).

In fact, the inclusion of preprints among database coverage (a relevant topic right now, during the COVID era) and the use of Altmetric measures are competitive advantages that make it attractive for scientometricians (Silva; Vanz, 2019; Melicherová; Ondrišová; Šušol, 2021). In this regard, Altmetric measures also showed a growing behavior during the period under study, especially since 2016 (Figure 3). This was in correspondence with the boom of social networks and the use of popularity metrics to analyze web resources and online documents.

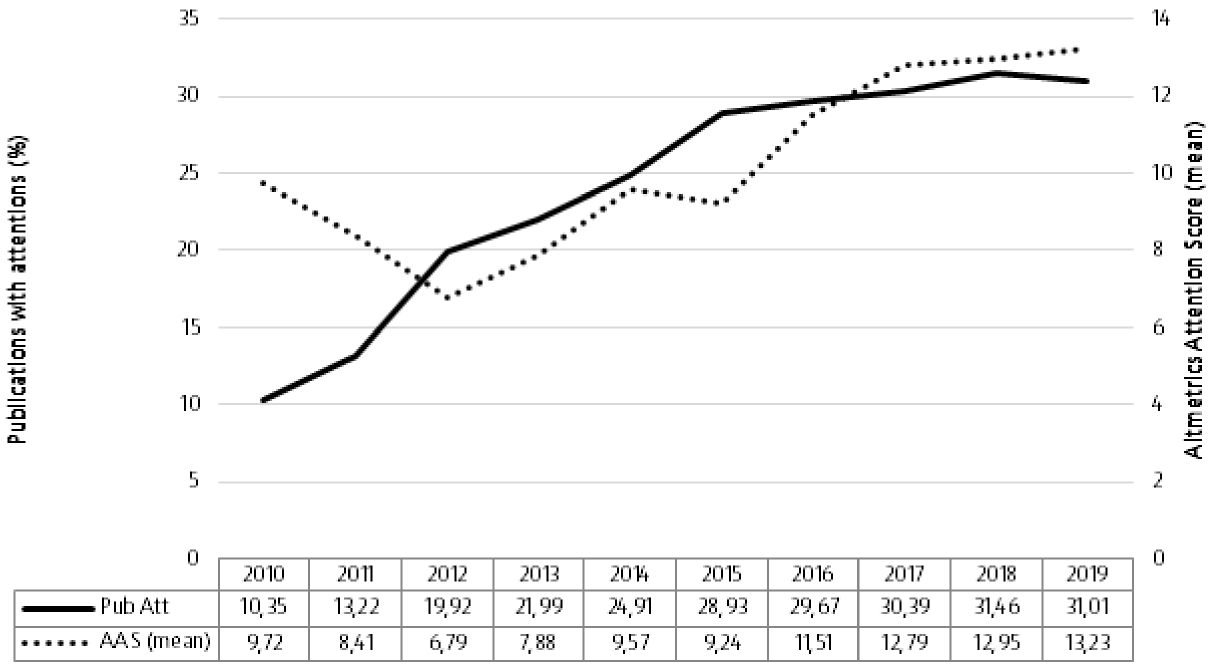


Figure 3 – Evolution of the Mexican publications with Altmetric Attention and Altmetric Attention Score during 2010-2019.
Source: The authors, based on Dimensions data; Digital Science and Research Solutions (2021).

Medical Sciences were predominant in the Mexican scientific output covered by Dimensions (Table 1). Medical literature covered 25% of the total Mexican output (a slightly higher ratio than Scopus and WoS (≈20%)) as well as 39.5% of citations received by Mexican papers. Biological Sciences showed the highest impact values (14.27 citations per document), with also a high proportion of publications with Altmetric Attention. Physical Sciences achieved the highest FCR (2.02, clearly higher than mean citation of the field). And Environmental Sciences reached the highest AAS (Table 1).

Table 1 — Raw data calculated for 22 major fields of the Mexican scientific production during 2010-2019.

1 of 2

Major fields (dimensions)	Npub	Npub (%)	Ncit	Ncit (mean)	FCR	Pub Att (%)	AAS
01 - Mathematical Sciences	11,479	5.9	86,790	7.56	1.73	17.98	5.27
02 - Physical Sciences	15,187	7.8	207,707	13.68	2.02	35.75	8.61
03 - Chemical Sciences	16,709	8.6	179,820	10.76	1.21	23.37	5.07
04 - Earth Sciences	5,156	2.6	64,256	12.46	1.5	33.49	15.54
05 - Environmental Sciences	6,326	3.2	85,737	13.55	1.37	38.57	25.92
06 - Biological Sciences	30,148	15.5	430,208	14.27	1.35	43.52	13.78
07 - Agricultural and Veterinary Sciences	5,971	3.1	75,210	12.6	1.82	30.83	11.23

Table 1 – Raw data calculated for 22 major fields of the Mexican scientific production during 2010-2019.

2 of 2

Major fields (dimensions)	Npub	Npub (%)	Ncit	Ncit (mean)	FCR	Pub Att (%)	AAS
08 - Information and Computing Sciences	12,594	6.5	79,463	6.31	1.3	12.3	4.48
09 – Engineering	27,503	14.1	267,446	9.72	1.41	14.75	4.12
10 – Technology	4,096	2.1	35,083	8.57	1.19	17.82	3.84
11 - Medical and Health Sciences	48,979	25.1	590,571	12.06	1.49	34.6	13.79
12 - Built Environment And Design	546	0.3	3,716	6.81	1.32	28.94	6.54
13 – Education	2,787	1.4	5,174	1.86	0.6	13.02	4.44
14 - Economics	3,234	1.7	13,570	4.2	0.84	17.5	7.48
15 - Commerce, Management, Tourism and Services	2,113	1.1	12,791	6.05	1.19	18.41	5.58
16 - Studies in Human Society	5,645	2.9	21,805	3.86	0.88	24.92	10.29
17 - Psychology and Cognitive Sciences	4,996	2.6	32,844	6.57	1.06	29.02	9.9
18 - Law and Legal Studies	849	0.4	1,261	1.49	0.61	16.84	6.03
19 - Studies in Creative Arts and Writing	255	0.1	501	1.96	0.55	18.43	5.49
20 - Language, Communication and Culture	2,080	1.1	3,675	1.77	0.53	10.29	13.16
21 - History and Archaeology	1,918	1.0	4,827	2.52	0.81	15.48	21.52
22 - Philosophy and Religious Studies	1,597	0.8	1,711	1.07	0.46	10.52	3.33

Source: The authors, based on Dimensions data; Digital Science and Research Solutions (2021).

However, the multidimensional approach allows us to compare the Mexican effort with the world ratio in each major field with the aim to determine the areas where Mexico achieved a relative leadership (Figure 4).

Major fields were clustered according to the behavior of six relative measures (Figure 4a). The clusters with a darker color in the density graphs represent the areas in which Mexican scientific production stands out (Figure 4b). The major fields located in the lower half of the graphs showed a better performance than the world in most of the indicators analyzed.

Agricultural and Veterinary Sciences and Environmental Sciences experimented the best performance in almost all measures. Physical sciences and Mathematical sciences also showed values higher than the world, leading the FCR and Pub Att measures. History and Archeology achieved relevant citation-based indicators, such as RI and FCR, and it was also the area with the highest AAS. Biological Sciences and Earth Sciences completed the number of areas with better national efforts. Medical and Health Sciences in Mexico showed values similar to the world, and some subjects only highlighted using AI (Chemical Sciences and Engineering), RI (Language, Communication and Culture), FCR (Built Environment and Design), and Pub Att (Technology and Information and Computing Sciences) (Figure 4).

A more detailed picture is obtained when the behavior of the 151 subfields where Mexico has published its research is analyzed. The subfields were structured into 29 clusters (Figure 5a).

Density maps show values similar or higher to the world in almost all clusters. Only clusters C29 (1901 – Art Theory and Criticism, 2099 – Other Language, Communication and Culture, and 2199 – Other History and archeology), C22 (1204 – Engineering Design and 2204 – Religion and Religious Studies) and C21 (1506 - Tourism, 1699 – Other Studies of Human Society, 1801 – Law, 1904 – Performing Arts and Creative Writing and 2003 – Language Studies) showed low values of

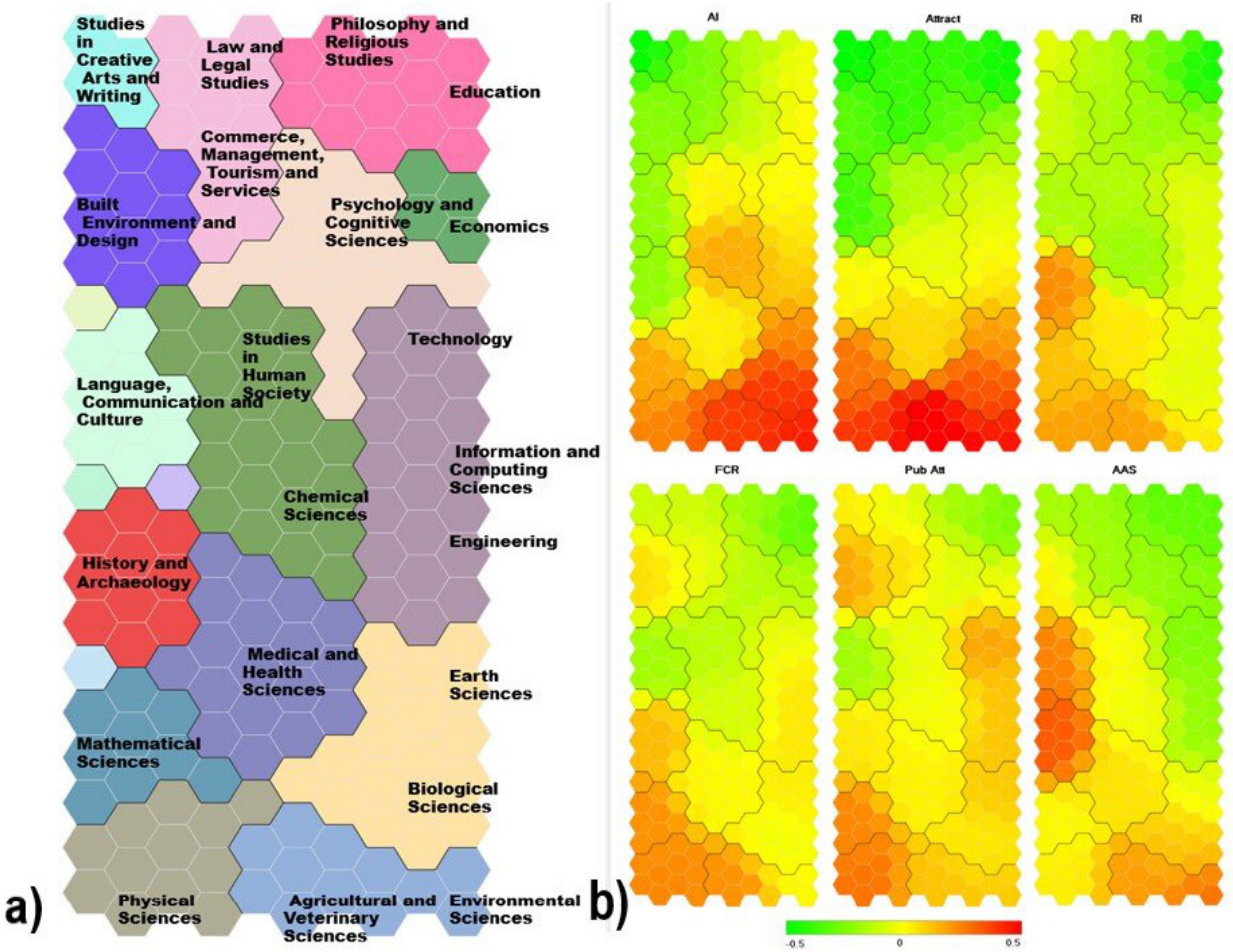


Figure 4 – Thematic multidimensional profile of the Mexican scientific output during 2010-2019. 22 major fields: a) Performance-based clusters; b) Density maps of relative indicators calculated for each cluster (Arencibia-Jorge et al., 2021).
Source: The authors, based on Dimensions data; Digital Science and Research Solutions (2021).

the six relative indicators. The rest presented similar or higher performances than the world in at least one bibliometric dimension.

Five clusters stand out for their good performance according to all the indicators. For instance, C8 (0105 - Mathematical Physics, 0202 – Atomic, Molecular, Nuclear, Particle and Plasma Physics and 0701 – Agriculture, Land and Farm Management), C9 (0201 – Astronomical and Space Sciences, 0501 – Ecological Applications, 0607 – Plant Biology, 0703 – Crop and Pasture Production and 0705 – Forestry Sciences), C10 (0101 – Pure Mathematics, 0102 – Applied Mathematics, 0103 – Numerical and Computational Mathematics, 0299 – Other Physical Sciences, 0402 – Geochemistry, 0503 - Soil Sciences, 0604 – Genetics, 0799 – Other Agriculture and Veterinary Sciences, 0999 – Other Engineering, 1117 – Public Health and Health Services and 1505 – Marketing), C3 (0502 – Environmental Science and Management, 0602 – Ecology, 0603 – Evolutionary Biology, 0608 – Zoology, and 0699 – Other Biological Sciences) and C2 (1902 – Film, Television and Digital Media and 2002 – Cultural Studies).

AI was the only negative indicator in cluster C7 (0706 - Horticultural Production, 1903 – Journalism and Professional Writing, 2001 – Communication and Media Studies, and 2101 – Archeology). This cluster showed the highest values of Pub Att and AAS, which confirm the

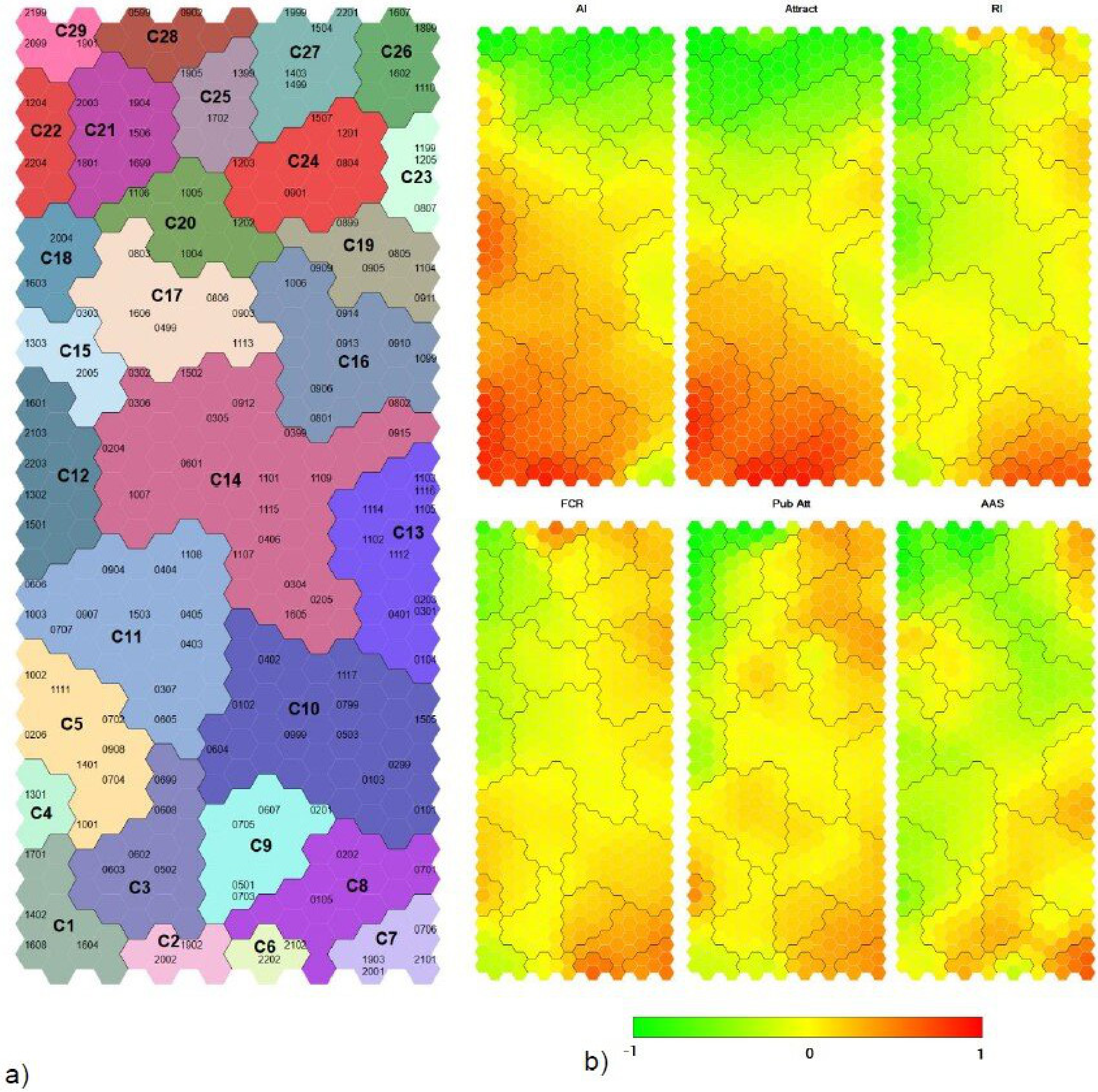


Figure 5 – Thematic multidimensional profile of the Mexican scientific output during 2010-2019. 151 Subfields: a) Performance-based clusters; b) Density maps of relative indicators calculated for each cluster.
Source: The authors, based on Dimensions data; Digital Science and Research Solutions (2021).

relevance of this subfields for social networks and mass media. On the other hand, clusters C26 (1110 – Nursing, 1602 – Criminology, 1607 - Social Work and 1899 – Other Law and Legal Studies) and C23 (0807 – Library and Information Studies, 1199 – Other Medical and Health Sciences and 1205 – Urban and Regional Planning) were very actives in RI and altmetrics, with lower values of AI and Attract.

Some clusters showed a relevant performance in activity and impact, with a less leading role in AAS, such as C6 (2102 – Curatorial and Related Studies and 2202 – History and Philosophy of Specific Fields), C4 (1301 – Education Systems), C5 (0206 - Quantum Physics, 0704 – Fisheries

Sciences, 0908 — Food Sciences, 1001 — Agricultural Biotechnology, 1002 — Environmental Biotechnology, 1111 — Nutrition and Dietetics and 1401 — Economic Theory) and C11 (0307 — Theoretical and Computational Chemistry, 0403 — Geology, 0404 — Geophysics, 0405 — Oceanography, 0605 — Microbiology, 0606 — Physiology, 0707 — Veterinary Sciences, 0904 — Chemical Engineering, 0907 — Environmental Engineering, 1003 — Industrial Biotechnology, 1106 — Human Movement and Sport Science and 1503 — Business and Management). Despite its good performance on activity and Attract, clusters C1 (1402 — Applied Economy, 1604 — Human Geography, 1608 — Sociology and 1701 — Psychology) and C12 (1302 — Curriculum and Pedagogy, 1501 — Accounting, Auditing and Accountability, 1601 — Anthropology, 2103 — Historical Studies and 2203 — Philosophy) showed lower values of RI, FCR, Pub Att and AAS.

Areas with values similar to the world in all indicators were located in the middle of the figure, covering 24.5% of Mexican subfields, and led by cluster C14 (0204 - Condensed Matter Physics, 0205 — Optical Physics, 0302 — Inorganic Chemistry, 0304 — Medicinal and Biomolecular Chemistry, 0305 — Organic Chemistry, 0306 - Physical Chemistry, 0399 — Other Chemical Sciences, 0406 — Physical Geography and Environmental Geosciences, 0601 — Biochemistry and Cell Biology, 0802 — Computation Theory and Mathematics, 0912 — Materials Engineering, 0915 — Interdisciplinary Engineering, 1007 — Nanotechnology, 1101 — Medical Biochemistry and Haematology, 1107 — Immunology, 1109 — Neurosciences, 1115 — Pharmacology and Pharmaceutical Sciences, 1502 — Banking, Finance and Investment and 1605 — Policy and Administration), which is the greatest cluster. These areas also covered clusters C16 (0801 — Artificial Intelligence and Image Processing, 0906 — Electrical and Electronic Engineering, 0909 — Geomatic Engineering, 0910 - Manufacturing Engineering, 0913 - Mechanical Engineering, 0914 — Resource Engineering and Extractive Metallurgy, 1006 — Computer Hardware and 1099 — Other Technology) and C13 (0104 — Statistics, 0203 — Classical Physics, 0301 — Analytical Chemistry, 0401 - Atmospheric Sciences, 1102 — Cardiorespiratory Medicine and Haematology, 1103 — Clinical Sciences, 1105 — Dentistry, 1112 — Oncology and Cardiogenesis, 1114 — Paediatrics and Reproductive Medicine and 1116 — Medical Physiology).

In some areas, Mexico outperformed the world according to a certain dimension. For instance, cluster C27 (1403 — Econometrics, 1499 — Other Economics, 1504 — Comercial Services, 1999 — Other Studies in Creative Arts and Writing and 2201 — Applied Ethics) showed slightly higher values according to RI, FCR and Pub Att. Clusters C19 (0805 — Distributed Computing, 0899 — Other Information and Computing Sciences, 0905 — Civil Engineering, 0911 — Maritime Engineering and 1104 — Complementary and Alternative Medicine) and C28 (0599 — Other Environmental Sciences and 0902 — Automotive Engineering) only highlighted in RI and FCR values. The AI of clusters C15 (0303 — Macromolecular and Materials Chemistry, 1303 — Specialist Studies in Education and 2005 — Literary Studies), C17 (0499 — Other Earth Sciences, 0803 — Computer Software, 0806 — Information Systems, 0903 — Biomedical Engineering, 1113 — Ophtalmology and Optometry and 1606 - Political Science) and C18 (1603 — Demography and 2004 — Linguistics) was slightly higher to the world. C17 also highlighted in Pub Att, while C18 reached a higher AAS. Cluster C25 (1399 - Other Education, 1702 — Cognitive Sciences and 1905 — Visual Arts and Crafts) reached its highest performances according to FCR and Pub Att.

Finally, clusters C24 (0804 — Data Format, 0901 — Aerospace Engineering, 1201 — Architecture, 1203 - Design Practice and Management and 1507 — Transportation and Freight Services) and C20 (1004 — Complementary and Alternative Medicine, 1005 — Dentistry, 1106 — Human Movement and Sport Science and 1202 — Building) stood out for high values of Pub Att.

Discussion

Standard bibliometric measures applied to the Mexican scientific output always reveal a profuse activity in Medical and Health Sciences, which is not far from reality (Lancho-Barrantes; Cantú-Ortiz, 2019). In fact, 25% of papers and almost 40% of citations covered by Dimensions belong to this research area. However, our study reveals that Mexican physicians' research has a similar behavior to the world output.

The use of relative indicators and the construction of a Mexican multidimensional thematic profile based on Dimensions allowed to obtain a new perspective of the research areas in which Mexican authors have produced. The neural network-based technique, previously developed to analyze the Mexican higher education institutions (Villaseñor; Arencibia-Jorge; Carrillo-Calvet, 2017), has been revealing new behavior patterns that make comparable the indices reached by the different areas in relation to the world. On the other hand, Altmetric indicators' inclusion breaks the traditional approach based only on citations and offers a new variable that reflects an underestimated pattern ten years ago that is gaining more importance every day.

The fact that Mexican research on History and Archeology has shown RI, FCR and AAS values considerably higher than the world average during the analyzed decade should not surprise anyone. Mexico is the cradle of two of America's great civilizations and the world: the Mayan and the Aztec cultures. Mexican history had strong links with world history after the Spanish conquest, and the Mexican revolution was a milestone during the twentieth century (Arencibia-Jorge *et al.*, 2021). However, the subfield analysis allowed us to identify that archaeologists were primarily responsible for this behavior. Despite the lower AI (Mexican archeologists publish less than their world counterparts in scientific journals covered by Dimensions), the impact and Altmetric measures expose high-quality Mexican research relevant to the media.

Mexican researchers on Environmental Sciences and Agricultural and Veterinary Sciences also showed a remarked performance. Particularly, in Environmental Sciences, our results demonstrated Mexican efforts during the decade to solve the national environmental problems. In a previous report, two Romanian authors included Mexico among a group of countries with an acceptable environmental quality, but with bibliometric indicators having lower performance, based on a high environmental performance index and a low index of publication per population (Dragos; Dragos, 2013). However, publication per population cannot be used as a proxy to measure environmental research effectiveness. The current research put the focus on the national effort vs. the world efforts, and probably the good performance of Mexican research in this area could have a positive effect on the Mexican environmental performance index value.

Physics and Mathematics are specialties where Mexico has developed relevant research, which confirmed previous bibliometric reports (Collazo-Reyes; Luna Morales; Russell, 2004; del Río; Russell; Juárez, 2020; Verma *et al.*, 2021). However, humanities and social sciences still showed low performances. With the solitary exception of History and Archeology, Mexican research on Creative Arts, Writing, Law and Legal Studies, Philosophy, Religion, Education, Economics, Commerce, Management, Tourism and Services exhibited values under the world average. Nevertheless, the inclusion of subfields in the analysis allows us to identify interesting topics on Social Sciences and Humanities with remarkable performances, such as Cultural Studies (C2), Journalism (C7), Education Systems (C4) or Communication and Media Studies (C7), and even mean performances in areas related to Banking, Finance and Investment or Policy and Administration (both in C13)

Another interesting issue related to the neural network-based subfields approach is the possibility to identify similarities between different disciplines. The fact that Demography and

Linguistics (see cluster C18) or Biomedical Engineering and Political Science (see cluster C17) share the same bibliometric cluster talks about the methodology's efficiency to analyze specific characteristics of scientific activities and common links among research practices in different knowledge domains.

Finally, it is important to remark that Mexican coverage in Dimensions could be affected by documents without country affiliation in the database, as noted by Guerrero-Bote *et al.* (2021). However, this is a relatively new database, and it is expected a fast improvement and development during the next years.

Conclusions

Mexican scientific production experimented an exponential growth during the period 2010-2019. The characteristics of the 22 major fields and 151 subfields of Dimensions were analyzed through a multidimensional approach based on ANN. Agriculture and veterinary sciences, Environmental Sciences, Physical sciences, Biological Sciences, Earth Sciences, Mathematical Sciences and, surprisingly, History and Archeology achieved the best bibliometric performances in relation to the world. SOM-based science mapping offered a better comprehension of Mexican research areas during the last decade, allowing the analysis of specific characteristics and common links among research practices in different Mexican knowledge domains. Altmetric indicators offered an interesting approach that would be seriously analyzed for future research assessment policies.

References

Alcazar Farias, E.; Lozano Guzman, A. Historical development of Science and Technology Indicators advances in Latin America and Mexico. *Revista Espanola de Documentacion Cientifica*, v. 32, n. 3, p. 119-126, 2009. Doi: https://doi.org/10.3989/redc.2009.3.676.

Aleixandre, J. L. *et al.* Viticulture and oenology scientific research: The Old World versus the New World wine-producing countries. *International Journal of Information Management*, v. 36, n. 3, p. 389-396, 2016. Doi: https://doi.org/10.1016/j.ijinfomgt.2016.01.003.

Arencibia-Jorge, R. *et al.* Thematic multidimensional profile of Mexican scientific output in Dimensions 2010-2019. *In*: W. Glanzel, S. *et al.* (ed.). 18th International Conference on Scientometrics and Informetrics. Leuven, Belgium: *International Society for Scientometrics and Informetrics*, 2021. p. 1437-1438.

Arvanitis, R.; Russell, J. M.; Rosas, A. M. Experiences with the national citation reports database for measuring national performance: the case of Mexico. *Scientometrics*, v. 35, n. 2, p. 247-255, 1996. Doi: https://doi.org/10.1007/bf02018482.

Braun, T.; Schubert, A. Dimensions of scientometric indicator datafiles: World science in 1990-1994. *Scientometrics*, v. 38, n. 1, p. 175-204, 1997. Doi: https://doi.org/10.1007/bf02461130.

Bravo Vinaja, A. *Análisis bibliométrico de la producción científica de México en ciencias agrícolas a través de las bases de datos internacionales*: agricola, agris, cab abstracts, science citation index, social science citation index y tropag & rural, en el período 1983-2002. Tesis (Doctorado en Biblioteconomía y Documentación) – Universidad Carlos III, Madrid, 2005. Available at: http://hdl.handle.net/10016/683. Cited: Feb. 20, 2021.

Castillo-Pérez, J. J.; Muñoz-Valera, L. Producción científica mexicana sobre influenza, 2000-2012. *Salud Pública de Mexico*, v. 56, n. 5, p. 424-425, 2014.

Chinchilla-Rodriguez, Z. *et al.* Latin American scientific output in Public Health: combined analysis using bibliometric, socioeconomic and health indicators. *Scientometrics*, v. 102, n. 1, p. 609-628, 2015. Doi: https://doi.org/10.1007/s11192-014-1349-9.

Collazo-Reyes, F.; Luna-Morales, M. E.; Luna-Morales, E. Change in the publishing regime in Latin America: from a local to universal journal, Archivos de investigación Médica/Archives of Medical Research (1970-2014). *Scientometrics*, v. 110, n. 2, p. 695-709, 2017. Doi: https://doi.org/10.1007/s11192-016-2207-8.

Collazo-Reyes, F.; Luna-Morales, M. E.; Russell, J. M. Publication and citation patterns of the Mexican contribution to a "Big Science" discipline: Elementary particle physics. *Scientometrics*, v. 60, n. 2, p. 131-143, 2004. Doi: https://doi.org/10.1023/b:scie.0000027676.41604.e9.

Collazo-Reyes, F. *et al.* Publication and citation patterns of Latin American & Caribbean journals in the SCI and SSCI from 1995 to 2004. *Scientometrics*, v. 75, n. 1, p. 145-161, 2008. Doi: https://doi.org/10.1007/s11192-007-1841-6.

de Arenas, J. L.; Castanos-Lomnitz, H.; Arenas-Licea, J. Significant Mexican research in the health sciences: A bibliometric analysis. *Scientometrics*, v. 53, n. 1, p. 39-48, 2002. Doi: https://doi.org/10.1023/a:1014879803333.

del Río, J. A.; Russell, J. M.; Juárez, D. Applied physics in Mexico: mining the past to predict the future. *Scientometrics*, v. 125, n. 1, p. 187-212, 2020. Doi: https://doi.org/10.1007/s11192-020-03639-7.

Digital Science & Research Solutions. Dimensions. 2018. Available at: https://www.dimensions.ai/. Cited: Feb. 20, 2021.

Dragos, C. M.; Dragos, S. L. Bibliometric approach of factors affecting scientific productivity in environmental sciences and ecology. *Science of the Total Environment*, v. 449, n. 1, p. 184-188, 2013. Doi: https://doi.org/10.1016/j.scitotenv.2013.01.057.

Frame, J. D. Mainstream research in Latin America and the Caribbean. *Interciencia*, v. 2, p. 143-148, 1977.

Gantman, E. R.; Fernandez Rodriguez, C. J. Academic literature in the field of management and organizational studies in Spanish-speaking countries: A bibliometric analysis of the output in journals included in the Latindex-Catalogo database (2000-2010). *Investigacion Bibliotecologica*, v. 31, n. 72, p. 39-61, 2017. Doi: https://doi.org/10.22201/iibi.0187358xp.2017.72.57823.

Glänzel, W. Science in Scandinavia: a bibliometric approach. *Scientometrics*, v. 48, n. 2, p. 121-150, 2000. Doi: https://doi.org/10.1023/a:1005640604267.

Gontijo, M. C. A.; Hamanaka, R. Y.; de Araujo, R. F. Research data management: a bibliometric and altmetric study based on Dimensions. *Iberoamerican Journal of Science Measurement and Communication*, v. 1, n. 3, p. 1-19, 2021. Doi: https://doi.org/10.47909/ijsmc.120.

Guerrero-Bote, V. P. *et al.* Comparative analysis of the bibliometric sources Dimensions and Scopus: An approach at the country and institutional levels. *Frontiers in Research Metrics and Analytics*, v. 5: 593494, p. 1-19, 2021. Doi: https://doi.org/10.3389/frma.2020.593494.

Guzmán Sánchez, M. V.; Sotolongo Aguilar, G. Bibliometric study on vaccines (1990-1995) part i: scientific production in iberian-american countries. *Scientometrics*, v. 43, n. 2, p. 189-205, 1998. Doi: https://doi.org/10.1007/bf02458407.

Kohonen, T. Essentials of the self-organizing map. *Neural networks*, v. 37, n. 1, p. 52-65, 2013. Doi: https://doi.org/10.1016/j.neunet.2012.09.018.

Lancho-Barrantes, B. S.; Cantú-Ortiz, F. J. Science in Mexico: a bibliometric analysis. *Scientometrics*, v. 118, n. 2, p. 499-517, 2019. Doi: https://doi.org/10.1007/s11192-018-2985-2.

Melicherová, M.; Ondrišová, M.; Šušol, J. Bibliometrics versus altmetrics: Researchers' attitudes in Slovakia. *Iberoamerican Journal of Science Measurement and Communication*, v. 1, n. 1, 002, 2021. Doi: https://doi.org/10.47909/ijsmc.11.

Montero y López Lena, M. Scientific productivity in environmental psychology in Mexico - A bibliometric analysis. *Environment and Behavior*, v. 29, n. 2, p. 169-197, 1997. Doi: https://doi.org/10.1177/001391659702900202.

Luna Morales, M. E.; Luna Morales, E.; Sanchez Martinez, U. Patterns of Scientific Production and Impact of the International Maize and Wheat Improvement Center (CIMMYT) between 1966 and 2010. *Investigación Bibliotecológica*, v. 27, n. 60, p. 97-124, 2013.

Macias-Chapula, C. A. Comparative analysis of health public policy research results among Mexico, Chile and Argentina. *Scientometrics*, v. 95, n. 2, p. 615-628, 2013. Doi: https://doi.org/10.1007/s11192-012-0855-x.

Perez-Santos, J. L. M.; Anaya-Ruiz, M. Mexican Breast Cancer Research Output, 2003-2012. *Asian Pacific Journal of Cancer Prevention*, v. 14, n. 10, p. 5921–5923, 2013. Doi: https://doi.org/10.7314/APJCP.2013.14.10.5921.

Sierra-Flores, M. M. *et al.* The productivity of Mexican astronomers in the field of outflows from young stars. *Scientometrics*, v. 81, n. 3, p. 765–777, 2009. Doi: https://doi.org/10.1007/s11192-008-2264-8.

Silva, R. D. C., Vanz, S. A. D. S. Impacto de altmetrics sobre a visibilidade de artigos em acesso aberto da enfermagem brasileira: um estudo de caso. *Transinformação*, v. 31, e190025, 2019. Doi: https://doi.org/10.1590/2318-0889201931e190025.

Sotolongo Aguilar, G.; Guzmán Sánchez, M. V.; Carrillo, H. ViblioSom: Visualización de información bibliométrica mediante el mapeo autoorganizado. *Revista Española de Documentación Científica*, v. 25, n. 4, p. 477-484, 2002. Doi: https://doi.org/10.3989/redc.2002.v25.i4.281.

Verma, R., *et al.* Forty years of Applied Mathematical Modelling: A bibliometric study. *Applied Mathematical Modelling*, v. 89, n. 2, p. 1177-1197, 2021. Doi: https://doi.org/10.1016/j.apm.2020.07.004.

Villaseñor, E. A.; Arencibia-Jorge, R.; Carrillo-Calvet, H. Multiparametric characterization of scientometric performance profiles assisted by neural networks: a study of Mexican higher education institutions. *Scientometrics*, v. 110, n. 1, p. 77-104, 2017. Doi: https://doi.org/10.1007/s11192-016-2166-0.

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Collaborators

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