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Evaluation of the scientific impact, productivity and biological age based upon the h-index in three Latin American countries: the materials science case

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We discuss the scientific impact of Latin American scientists in the field of materials science. The analysis is based on the h-index as the scientometric index used to quantify the scientific productivity of an individual. In particular, we focus our analysis in *México, Chile* and *Colombia*. We compare the level of productivity between all these countries. We also analyzed the h-index as function of the biological age, by using the first year of publication of a given scientists as a reference and discussed the general distribution of its quantification. We do not find a clear relationship between these two quantities. Based in our results we propose some political measures that these countries could implement to improve productivity as well as scientific development in this field.

1 Introduction

An informed selection and promotion policy of adequate personnel has always been present in every human enterprise. However, what used to be implemented by rather crude procedures: old buddy references, personal interviews, letters of recommendation, the so-called peer reviews, family connections or shear prejudice is now seen giving way to more objective and sophisticated procedures. These changes have many causes, among which the most relevant seem to be the massive size of many enterprises and institutions, which makes the traditional systems ineffective, and the demand for transparency that society is imposing both on the public and private sectors. Academia has not been a stranger to this evolution and the hiring and promotion of its members is increasingly approached on the basis of indices and other quantitative elements, rather than simply by routine faculty decisions based on "we know who is good and/or whom we want".

Thus, critical questions have arisen: How to determine the relevance of a particular topic? How to measure the scientific impact of a given scientists? How to validate the quality of the scientific contribution of a country? How to judge an academic department? Just recently there have been several different attempts to develop a balanced approach. In particular, an index which quantifies the impact of scholarly achievements and embodies a figure of merit was put forward by Jorge E. Hirsch: the h-index, defined as *the number of publications of a given author with at least h citations* [1–6]. It constitutes a balance between the number of papers published by a given author and the number of citations the author obtains for his/her work. Of

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course, it is not the only epistometric measure and it has some limitations [7–11]. Between the recognized problems are: not very appropriate for scientists with low number of papers, handicapped for scientists with only some outstandingly cited papers [7], underestimation of the achievement of scientists with a given strategy (do not publish high number of papers but with large international impact), the use of the h-index to assess the scientific career of a single individual [9], biasing across disciplines [10], etc. Even though, many different problems have been reported, it is well recognized as an improvement in relation to previous indices, able to capture the scientific information on the productivity and impact of a large body of people. It is also very effective when used to compare researchers working in the same field and it does give quite reliable information about the scientific status of a given topic by country, university and/or department. Its advantages were very soon recognized [3–6] and now it is quite frequently used in important decisions like tenure track positions, the election to scientific bodies such as the National Academy of Science of the United States, the British Royal Society, the assignment of research grants, prizes, etc. While the h-index does not necessarily rank properly a single individuals achievements and potentials it establishes a standard which is useful as a general guideline. The h-index does, however, depend in an approximately linear way on the scientific age of the scientist, defined as the number of years elapsed since the first publication or the completion of a PhD [2].

In this article, we present an analysis of the field of materials science in three different Latin American countries. Our main objective is to focus the attention of the scientific community on how these countries are doing in the field, to suggest some measures and ideas on how to improve the situation, and how international organizations can engage in creating opportunities for global, rather than personal, achievements. However, it is not our intention to criticize the policies and efforts that each country is carrying out in order to support and improve their scientific communities. In addition, we also intend to establish if there is a relationship between the h-index and the researcher's age, and to contrast the statistical dependence for several Latin American countries. A similar assessment has been discussed in [10, 11] for many different scientific fields. We trust that our study will contribute to improve public policies in the region, as well as provide some understanding of the scientific situation on those countries.

2 The Latin American region

Here we carry out this analysis for three countries of the Latin American region: *México, Chile* and *Colombia*. Each one of them is in a different geographical location and has different socio-cultural ideas and policies on how science has to be performed. México spends of the order of 0.41 % of the PIB (2006) for science and technology, whereas Chile spends 0.7 % (0.68 % in 2004) and Colombia 0.6 % (2004). The researcher index, defined as the number of researchers per thousand workers, is 1.03 (2005) for México, 2.03 (2004) for Chile and 0.24 (2004) for Colombia [12, 13]. Large differences, in size and otherwise, between México and other Latin American countries are quite apparent. In fact, we point out that in the case of México the researchers are officially classified according to their research career, and in these statistics only scientists with significant impact are included. In any case, it is quite apparent that most of the Latin American countries are quite far, as measured by the researcher index, from developed first world countries like Canada (7.2), Germany, Japan (10.4) and the USA (9.6), while in the same ballpark as Argentina (1.8) and Turkey (1.1). These figures indicate that even though there is a growth of the scientific presence in different Latin American countries, there is much room for improvement, and that the governments should consider policies to reduce this negative development potential by increasing the number of scientists in their respective nations.

To start our analysis on the different countries we have endeavored to detect all scientists working in the field of materials science, by looking into scientific societies, universities and so on. We did consider all departments, in all the three countries, with physics, chemistry, engineering and materials science majors in all universities throughout the given country, which offer these studies. For every department, we did analyze the researchers reported by the university on their web page and study every individual to determine his/her production. Then, if a given researcher did publish at least one paper in a materials science journal, where we have used the Journal Citation Report (annual publication by the ISI) to identify the journal, the scientist was included in the pool. For every individual we did consider all his/her production, independently if it was performed within the country or the department under consideration. The pool was completed by looking into scientific institutions data basis, such as the National Academies of Sciences, and/or within databases of governmental institutions. We do recognize that performing a classification in fields and subfields is not a trivial task mainly due the thin line between different fields, as it has been recognized and discussed for a particular case in [14]. Once the scientists were classified we used the ISI Web of Science database in the "General Search" mode [15]. After an author has been properly identified in the data base, ISI readily yields the citation report that we used in our analysis. We did ensure that the papers used to compute the h-index actually correspond to the author being searched, the community under consideration and to be within the time span between his/her first publication and March 2008. We should point out that this is not the first study for Mexican researches. Gonzalez-Bramila and Veloso have discussed the case for Mexican researches in a previous publication [16]. However, there are several differences with the present study: (i) we have gathered all our data from all available resources on the web, whereas they have used a database from the Mexican National System of Researchers (SNI), which are mostly classified in seven research fields (in particular, materials scientists can be part of at least two of those fields), (ii) our data has been obtained from the first year of publication up to 2008, which constitutes a more complete analysis than the data published in [16], (iii) we do focus on a single area of science, recognizing that different fields have different citation trends and publication norms (see, for example, [14]). Therefore, in what follows, we only discuss the data obtained from our own search.

3 México

The first country we analyze is México. The overall h-index distribution is shown in Fig. 1. The whole distribution can be fitted by a Lorentzian function with a peak value of 6.0, an average value of 6.68 and a tail that extends up to 44. The whole materials science community in México is quite diverse as can be observed from the right panel in Fig. 1. As shown, the first publication distribution has a peak around 1990, but with a very slow decay afterwards, which points out towards a slow community renewal, maybe due to

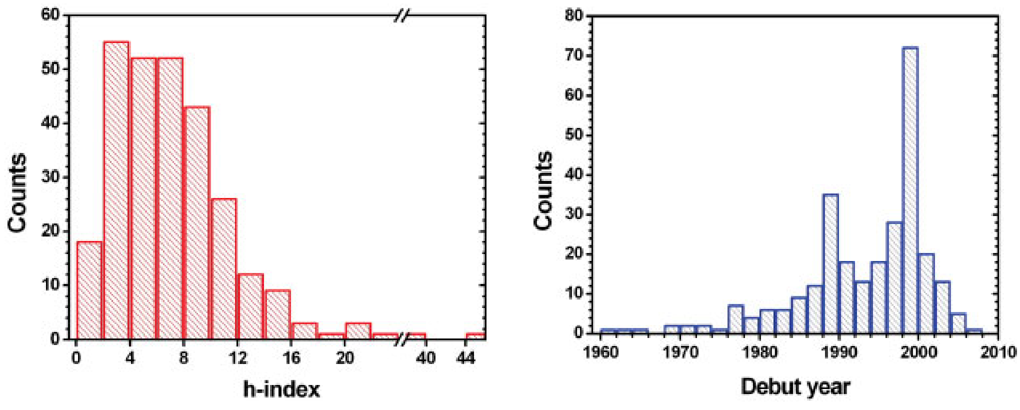

Fig. 1 (online colour at: www.ann-phys.org) Left panel: h-index histogram for materials research scientists in México. Right panel: year of first publication histogram. Both panels are for researches belonging to the Mexican National Researcher System (SNI in Spanish, see text for explanation).

a slow decrease on available positions. There is a second peak 1998, where it seems, the total number of positions was also increased but again there is a decrease which remains nowadays.

In particular, in México researchers are categorized under a system called “Sistema Nacional de Investigadores (SNI)” (National Researcher System) created in 1984. There are basically four levels and the categorization is decided according to objective data such as number of papers, citations, graduate students trained, etc, in addition to some other more subjective criteria such as the contribution to the establishment of research groups, experience, international recognition, etc. They are known as candidates, level I, level II and level III (we do not discuss results at the candidate level in this article, since they are only new comers with very recently awarded PhD’s). In general terms, scientists belonging to SNI level I have h-index average of 4.48, an indication of researches starting the scientific career. As a researcher is promoted to higher SNI levels, the h-index also increases according to the scientific impact of previous publications. The average value for SNI level II is 6.77, whereas it is 12.77 for level III. It is interesting to note that in level III, the disparity of the h-index is much larger than in the other levels, which manifests an increase of importance of academic criteria other than scientific impact, when a researcher is promoted from level II to III.

In the case of level I, there is large number of scientists that started their careers around 1990 and another much larger group that started around 2000. This is correlated to an increase of hiring around that time, in many different Mexican institutions. However, it also indicates that there are a large number of researches which have more than 15 years of experience and who are not able to improve their SNI level. This could be related to scientific positions with a large administrative or teaching load, or maybe they are less-talented researchers which entered into the system and do not allow more talented newcomers to get into the system, as it has been suggested in [17] in its analysis for the Italian research system. The case of SNI level II is much clearer. The majority of researches published their first paper between 1996 and 2000, but also 33 % of them did so in the time span between 1980 and 1990. The distribution is bimodal with two clear peaks around 1990 and 2000. This indicates that there are different biological age generations belonging to this level and that both are publishing regularly. The generations of this level are the ones responsible for the bimodal distribution shown in Fig 1. In particular, we observe that a large number of materials scientists published their first paper between 1995 and 2000, and thus they are not really young scientists (with ages between 35 and 45). These scientists are the ones that probably did receive their PhD’s 10 years ago, but have been able to publish papers that generated a considerable degree of interest and attention. Of course the impact is expected to be correlated with experience.

In the case of SNI level II and III, the contribution to the h-index histogram is different. Whereas the level II spans a range between 6 and 22, the range of level III is significantly larger, going from 10 up to 44. Therefore, the promotion from level II to III seriously depends on scientific impact as well as other subjective factors, as the number of students trained, project management, leadership, etc. In general, for SNI level III, the average age is around 55 years (assuming that a scientist completes the PhD around 30). Therefore, the most qualified scientists in México are quite mature and have a fair impact in the area of materials science. We do not find a large difference between scientists at SNI II and SNI III levels, apart from age and probably experience, which is one of the subjective factors for promotion in this classification scheme. We should also point out that the h-index average of 12.77 for this level and 6.82 found for México as a whole, are quite reasonable [18]. We also notice that the tail of the distribution (i.e., scientists with an h-index larger than 15) is quite significant, indicating personal efforts by scientists with large impact, maybe due to strong international collaborations, large scientific groups and, maybe, in some cases, due to a large number of self-citations. In general, the h-index distribution is much wider and there are quite a number of young successful researches within the range of 1995–2000, while there are other ones within ranges between 1975 and 1985. The whole analysis of the first publication distribution shows that the Mexican situation can be summarized as optimistic, with a large percentage of researches that started publishing after 1990 (a 20 %). Even though our analysis has been based on the h-index, it is important to say that maybe some of our conclusions for higher SNI levels are size-dependent. As the researchers get older, they receive more citations and increase the h-index, in comparison with younger researches. Therefore we will also perform analysis with other potential epistemometric indices in future publications, in particular to study the influence of including some papers with longer data, to determine how that can affect the whole productivity analysis.

We conclude that, in order to maintain this trend, it is required that positions be created not only for researchers starting their scientific careers, but also for scientists with much stronger experience (h-index larger than 12). It is also important that international collaborations be strengthened and that stronger collaborative efforts are established, in order to increase the number of scientists with large scientific impact.

4 Chile

The Chilean situation is somewhat ambiguous, as observed in Fig. 2. Whereas, the distribution of the h-index also seems to be Lorentzian, it has a much shorter tail than for México, with an average of 7.26, which is smaller than the general Mexican case, and with a scientific average of first publication date also larger than México (meaning a much more mature community). The average age for scientists in Chile seems to be of the order of 55 years, which draws attention to the fact that not sufficient young people have been incorporated into the system. Interestingly enough, there is an increasing slope for the first publication histogram, which is close to the time when the Chilean dictator Augusto Pinochet took power (1973), with a significant depletion afterwards. Once democracy was reestablished, in 1990, we do not detect a renewal of the scientific community, and even more, we find that the hiring process has decreased since then.

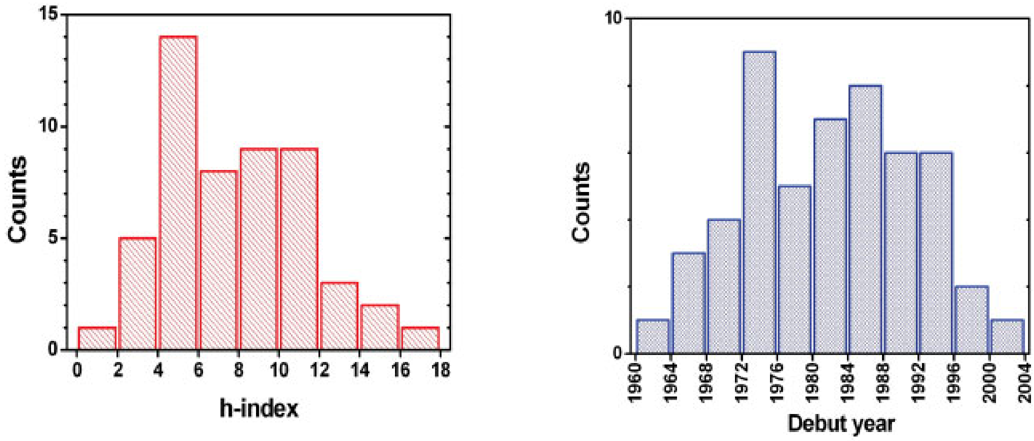

Fig. 2 (online colour at: www.ann-phys.org) Left panel: h-index histogram for Chile. Right panel: histogram of year of first publication.

Figure 2 also suggests that in order to increase the strength of the Chilean system, and to incorporate it in its economic development, two different tasks have to be undertaken: (i) to hire people with experience and with a significant scientific impact; and, (ii) to increase as well as the presence of young scientists, with a fair impact.

5 Colombia

The case of Colombia is also quite interesting, as noted in Fig. 3. From the sample we have studied, we can see that the age of first publication is increasing constantly up to 2000, when there is a clear drop. This constitutes an indicator that suggests the growth of the community seems to have lost steam around the year 2000, possibly due to lower priority given by the government to science policy in recent

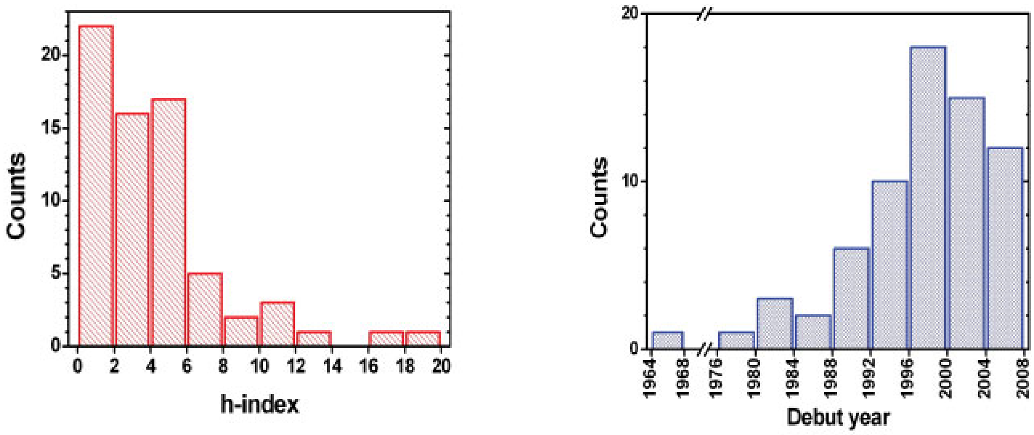

Fig. 3 (online colour at: www.ann-phys.org) Left panel: h-index histogram for Colombia. Right panel: histogram of year of first publication.

years. Thus, not many established scientists were hired, and it also seems that the scientists incorporated in the system for more than 15 years have not increased their productivity. The h-index has the lowest value among the three countries considered here (an average of 3.84), which indicates that even though the number of scientists increased, their impact is not going in the same direction. This strengthens our observation that, in the Colombian case, a political decision to hire more experienced researchers is urgent. This scenario can also be related to the fact that the research resources are concentrated on a few scientists, with no opportunity for younger ones to strengthen their international presence, and also to less attention by the government to educational issues as compared, for example, with national security programs like "Seguridad Democrática".

6 Comparison

To determine if there is a correlation between first time publication and h-index we summarize our findings in Fig. 4. We should point out that in this figure, we use a window that shows more clearly the correlations and some scientists with extraordinary h-index are left out (they are not more than 4). The data is quite scattered, but there is a general trend, where the h-index decreases as an inverse function of the year of first publication. A linear fit gives a slope of 0.003, which says that every 5 years the h-index decreases

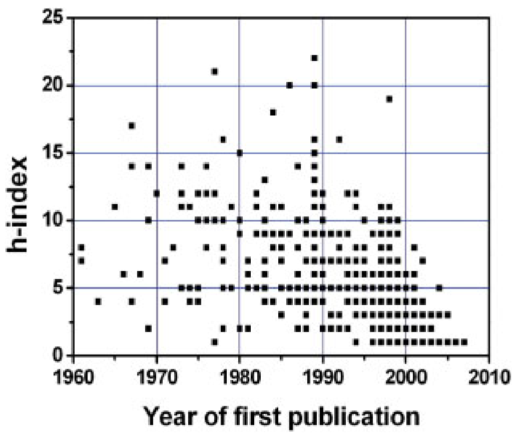

Fig. 4 (online colour at: www.ann-phys.org) Year of first publication against the h-index for México, Colombia and Chile in the field of materials science.

something like 3, but with a fitting index of 0.51 (also called coefficient of determination), which of course is related to the large data dispersion. Recently it was discussed that the h-index should depend on the time of first publication as $t^{1/2}$[2]. We did also test this hypothesis and again we saw that our dispersion was really large and the fitting index was 0.49. This could be related to the sample size but also to the lack of a general behavior in the impact on those countries in the materials science field. The dispersion is related to scientists out of the mainstream, which constitute a significant number. We also think that this lack of functional dependence between h-index and age for these three Latin-American countries could be related to the lack of clear rules for hiring, a real commitment of government agencies to offer support to long range research and strengthen the presence of groups and departments as a whole. Usually the large H-indices correspond to specific individuals, which have a large international network.

The growing number of articles in the field of materials science, in these three Latin American countries, as seen from the discussion of Figs. 1–4, is also supported by a different database [19] (which of course has different procedures for calculating the h-index when compared with the ISI data base). In the case of México, the number of papers in the field has grown from 372 in 1996, to 556 in 2001, and to 781 in 2006. This is strongly correlated with the experience gained by the different levels of the Mexican scientific community in the field of materials science. On the contrary, Chile and Colombia have sustained a smaller effort. Chile has gone from 111 articles in 1996, to 116 in 2001, and to 186 in 2006. The situation in Colombia is not much different; it has gone from 22 in 1996, to 48 in 2001, up to 112 in 2006. These big differences in the overall productivity are also captured by the total country 2006 h-index, which is of 42 for México, 22 for Chile and 18 for Colombia. It may be the case that even though the number of researchers has increased, some of them have been involved in a very large amount of educational and administrative responsibilities, taking them away from basic or applied research. In order to reverse this situation we suggest that the number of research positions be increased and the educational and administrative responsibilities more evenly distributed among junior and senior faculty members. Also, we request an increase of support from international agencies to improve the experience of scientists in the region, which will help some groups to increase their original research contributions and their scientific impact.

7 Conclusions

Above we reported an analysis, based on the h-index [1, 2], for three different Latin American countries: México, Chile and Colombia. In spite of their geographical and cultural diversity we established some correlations by means of this h-index analysis. The h-index obeys a Lorentzian distribution with respect to the number of scientists. It is clear that the age and number of scientists in every one of the countries analyzed is quite low when compared with more developed countries, and that in order to improve the worldwide presence and impact of Latin American materials science it is important to increase the funding for basic research.

We observe a very positive trend in the publication rate and impact in materials science in all of these Latin American countries, but they still rank quite far from the impact of first world countries such as Canada, with an h-index of 93, Japan with 121, and Germany with 138. These figures indicate the number of citations received by all the scientists from each of these countries, in the material science area, according to the Scopus classification [19]. However, it should also be mentioned that the number of papers published by these countries surpasses the ones of their Latin-American counterparts by more than an order of magnitude. This underscores the lack of a more experienced scientific community and their weak international contacts, a trend that has been starting to change for several reasons, like the decision of the European Community to allow researchers of foreign nations to apply to their scientific projects. Even though there are scientists in all of these countries with a very large impact (for example, there are materials scientists in the region with an h-index as large as 44) it is quite necessary to increase the number of more experienced ones (related to a large h-index, at least significantly larger than the country average).

Another suggestion would be to encourage the hiring of young scientists which have developed a strong international experience.

While we have been able to draw some valid conclusions from the analysis of the h-index, as applied to materials science in Chile, Colombia and México, it is certainly a bit early to use it as the sole basis for scholarly decisions (budget assignment, hiring and promotion) in Latin American nations. As it has been pointed out by other publications [1-6], the h-index is an important method, but is not the Holy Grail and other inputs and indicators should also be considered and implemented. In any case, it is important to include several epistemometric indices when a single individual is analyzed, and to have at hand a variety of inputs, as well as other indices, in addition to the one used here. Nevertheless, the acknowledgement of objective indicators, like the index we examined here, constitutes an improved starting point for the formulation and implementation of scientific policies, the hiring and promotion of scientific personnel, and the analysis of the weaknesses and strengths of the scientific communities we studied here, which certainly also applies to other less developed nations.

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