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Feature Article

Whither Latin America? Trends and Challenges of Science in Latin America

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Summary

Science in Latin America has experienced vigorous growth in the past decade, as demonstrated by the fact that the Latin American share of the world's scientific publications increased from 1.8% in 1991–1995 to 3.4% in 1999–2003. Significant growth has also taken place in the numbers of PhDs in science and engineering (S&E) awarded in Latin American countries in recent years, including those in the natural sciences. Importantly, albeit at different rates, growth has been verified in almost all countries in the region, indicating a general effort to promote the development of S&E. In most research fields, however, the recognition or relative impact of Latin American science, as measured by the average number of citations received by published articles (CpP), is still below world averages and much lower than in developed nations. We show that average CpP values for a set of 34 representative developing and developed countries correlate significantly with gross expenditure in research and development (GERD), with gross domestic product (GDP) per capita and with the number of researchers per million inhabitants (RpM). Among those countries, Latin American nations present some of the lowest average values of CpP (<6), GERD (≤1% of GDP) and RpM (<2,000). We also examined recent trends in scientific activity in Latin America, with focus on the natural sciences and on biochemistry and molecular biology (BMB). In terms of citation scores, publications in BMB compare favorably to those in other research fields within Latin America. At the same time, however, Latin American BMB is one of the areas for which relative impact – compared to developed nations or normalized to world averages – is lowest. These observations clearly indicate the need to establish effective policies to increase competitiveness in terms of the quality and international recognition of Latin American natural sciences in general, and BMB in particular, as opposed to merely increasing the absolute numbers of publications or the numbers of PhDs awarded in the region.

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Keywords Science; Latin America; biochemistry and molecular biology; scientific output.

Abbreviations BMB, Biochemistry and Molecular Biology; CpP, average number of citations per paper calculated for a country; G7, seven most industrialized nations of the world (USA, Canada, France, Germany, Italy, Japan and UK); GERD, gross expenditure in research and development; GDP, gross domestic product; HDI, Human Development Index; ISI/WoK, ISI Web of Knowledge; LatAm-3, top three science producing countries in Latin America: Brazil, Mexico and Argentina; OECD, Organization for Economic Cooperation and Development; PPP, purchase parity power; R&D, research and development; RpM, number of researchers per million inhabitants; S&E, science and engineering.

INVESTMENTS IN SCIENCE AND SCIENTIFIC OUTPUT

Several studies have related the wealth of nations to their science and engineering (S&E) output, in particular publications and citations (*1–3*). It is clear that richer nations – as defined by indicators such as the Human Development Index (HDI) or gross domestic product (GDP) per capita – produce more S&E papers which receive more citations in the scientific literature than developing countries. For example, North America (USA and Canada) produced 36.7% of the world's S&E papers in 2000, with a corresponding 37.2% of the world share of gross expenditure in research and development (GERD) (*4*). In the same year, Latin America accounted for 3.2% of the world's S&E publications and 2.9% of the world share of GERD. The correlation between investment and scientific output is further strengthened by the recent

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demonstration that S&E publications in 16 Latin American countries correlate linearly with research and development (R&D) spending in each country (*5*).

Another trend that has been discussed by several authors is the recent vigorous growth in Latin American output in terms of S&E publications (which increased from a total of 6,994 articles published in 1990 to 17,919 articles in 2004, as indexed in the Pascal database) and S&E doctoral degrees awarded per year (which increased from 1,695 to 7,815 in the same period) (*3, 6–8*). The participation of Latin America in world publications indexed in the Thomson's ISI-Web of Knowledge (ISI/WoK) database increased from 1.8% in 1991–1995 to 3.4% in 1999–2003 (*9*). The 10 most scientifically active Latin American countries significantly increased their publication outputs (ranging from 1.5- to 2.8-fold increases) between those two periods (Table 1). Indeed, for all Latin American countries the absolute number of ISI/WoK-indexed publications increased during the past 10 to15 years. Notably, the world share of publications also increased in the same period for the 10 most productive Latin American countries (Table 1). This indicates that, albeit at different rates, most countries in the region (especially those exhibiting stronger S&E profiles) have experienced significant growth in scientific activity during the past decade and a half. For example, in the case of Brazil, the leading nation in the continent in R&D spending (5.3 billion USD in 2004) and S&E publications, the world share of S&E publications more than doubled (from 0.7% to 1.5%) in that period (*10*).

An important issue that comes to mind, then, is whether science and technology are already growing at optimal rates in Latin America, or whether more effective policies should be devised to promote quantitative and/or qualitative growth. These two different possibilities have profound implications in terms of public policies for S&E in the region. If the first possibility is right, then it would seem logical to keep current policies in place, and all one would have to do is to wait a few more years to harvest the benefits of increased Latin American insertion into global S&E. If, however, the other possibility is correct, then governments, academies, foundations and scientific community must come up with alternative mechanisms to promote the necessary growth.

To begin to address this issue, we initially note that, compared to the top-10 Latin American countries, the world's top-5 countries in terms of scientific output exhibited considerably smaller increases (1.1- to 1.4-fold; Table 1) in the number of publications from 1991 to 2003. Moreover, while the North American (USA and Canada) share of world scientific publications decreased from 42% to 37% from 1990 to 2000 (*4*), the share for Latin America increased 1.9-fold (from 1.7% to 3.2%). Compared to the growth rates of other

Table 1
Scientific output (total number of publications) of selected nations

	Ranking 1991–1995	World share 1991–1995 (%)	Ranking 1999–2003	World share 1999–2003 (%)	Increase in total publication number
Top 5 in the world					
USA	1 (*)	34.89	1 (**)	31.48 ↓	1.1 fold
UK	2	8.85	3	8.93 ↑	1.2 fold
Japan	3	8.16	2	9.26 ↑	1.4 fold
Germany	4	7.38	4	8.49 ↑	1.4 fold
France	5	5.75	5	6.12 ↑	1.3 fold
Top 10 in Latin Am.					
Brazil	23 (•)	0.71	17 (••)	1.45 ↑	2.5 fold
Argentina	33	0.34	29	0.56 ↑	2.0 fold
Mexico	34	0.34	27	0.65 ↑	2.4 fold
Chile	45	0.19	39	0.27 ↑	1.7 fold
Venezuela	50	0.09	51	0.13 ↑	1.7 fold
Cuba	62	0.04	58	0.08 ↑	2.5 fold
Colombia	66	0.03	57	0.08 ↑	2.8 fold
Costa Rica	79	0.02	78	0.03 ↑	1.5 fold
Peru	87	0.02	82	0.03 ↑	1.7 fold
Uruguay	88	0.02	74	0.04 ↑	2.5 fold

Data from Glanzel et al. (*9*). (*)and (**): 1,174,603 and 1,284,415 publications, respectively. The increase in publication corresponds to the number of publications in 1999–2003 divided by publications in 1991–1995.
(•) and (••) correspond to 24,018 and 59,361 publications, respectively.

geopolitical regions (e.g., European Union, with an increase in world share from 34% to 40%; Asia, with an increase from 14.5% to 21%; and Africa, which maintained a constant share of 1.4% during the 1990–2000 decade), these numbers indicate that Latin American science in general has been growing at a substantially faster pace than science in the most scientifically-developed countries or even in other developing areas. Considering the investments in R&D by Latin American countries in the context of world investments, this result would seem to indicate that scientific policies in Latin America are promoting adequate use of money and resources.

The total number of publications, however, is only one (the simplest, and, as discussed below, possibly not the best) of several other indicators that can be used to evaluate the impact of S&E originating from a country or region. One such indicator is the impact or peer-recognition of each scientific publication, as measured by the average number of citations that an article receives in the published literature (*11*). This index allows a direct assessment of the 'visibility' of S&E produced in a given country, and it also provides a rough estimate of whether that S&E is of limited local/regional interest or is in pace with S&E carried out in other parts of the world. Qualitative improvement in the scientific output from a region or country should be accompanied by increased visibility of the published works. Unfortunately, the visibility of the S&E output from Latin America (expressed as the average ratio of citations per publication in a given period) is only increasing at a very modest pace (see below), and lags much behind the notable quantitative increases discussed above. It appears, therefore, that while current R&D policies in the region have been largely successful in stimulating quantitative growth, they have largely failed in terms of enhancing the international impact or visibility of Latin American science as a whole.

In the following sections, we first examine some of the factors underlying the robust quantitative expansion of Latin American S&E in recent years, and then proceed to a qualitative assessment of the performance of science in this region in a global context. Where applicable, and where data are currently available, we present a more detailed analysis of the development of the natural sciences, with special attention to biochemistry and molecular biology in the context of Latin American science.

DOCTORAL DEGREES IN S&E, RESEARCH JOBS AND R&D INVESTMENT

The number of S&E doctoral degrees awarded per year has increased significantly in Latin America, from 1,695 in 1990 to 7,815 in 2004 (Fig. 1A). It should be noted, however, that this growth has been markedly uneven among countries in the region. Largely due to a considerable governmental investment in fellowships for MSc and PhD candidates in the past couple of decades, as well as to an improved federal accreditation system for PhD-awarding courses (*12–14*), Brazil now concentrates most of the activity in terms of advanced training of human resources in the region. Indeed, S&E doctoral graduates from Brazil represented 59% of the total awarded in Latin America in 1990, and this proportion grew to a remarkable 78% in 2004 (*8, 10*). Because of the direct correlation between the number of PhD degrees awarded and S&E publication output ($r^2 = 0.95$ for Latin America as a whole from 1990–2004; data not shown), we feel

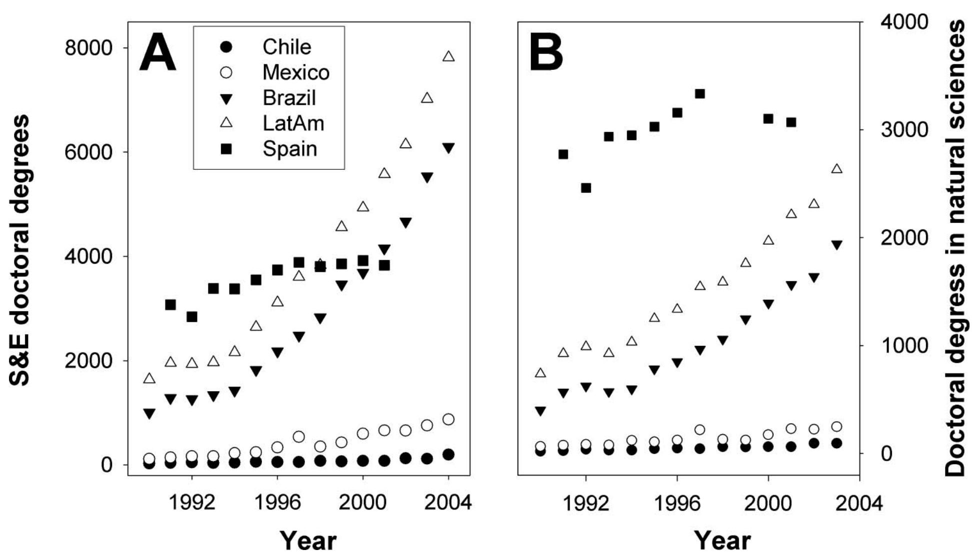

Figure 1. (A) Total number of S&E PhD degrees awarded per year in selected Latin American countries and in Spain. Data from RICYT (*10*). (B) Doctoral degrees in natural sciences awarded per year in the same countries. Chile increased from 20 PhD degrees in 1990 to 94 in 2003; Mexico increased from 66 to 249 in the same period.

that Latin American countries should pay close and immediate attention to their policies regarding the accreditation of qualified PhD-awarding courses and, importantly, to the availability of larger numbers of fellowships to enable good students to pursue advanced graduate training rather than moving immediately to the non-academic job market immediately after college.

Doctoral degrees in the natural sciences in Latin America have followed similar trends in overall growth in the past 10–15 years (Fig. 1B). In Fig. 1, data for selected Latin American countries are compared to data from Spain. We feel that Spain is of special relevance for a comparison with Latin American nations because of cultural similarities to most countries in the region and because of the intense growth in Spanish S&E publications from 1990 to 2004 (from 7,947 to 17,800 articles) and R&D investments in the same period (from 4.2 to 11.2 Billion USD PPP; for a definition of PPP, or purchase parity power, see http://en.wikipedia.org/wiki/Purchasing_power_parity). Fig. 1B shows that while Spain presented approximately stable values – averaging about 3,000 doctoral degrees in the natural sciences per year – Brazil, Chile and Mexico, as well Latin America as a whole, showed marked increases from 1990–2003.

Considering that a significant proportion of S&E PhD graduates are absorbed by universities or research institutes in Latin America (this is the case, for example, for 80% of Brazilian S&E PhD graduates; *15*), we investigated whether Latin American S&E output correlates with the number of research jobs in the region. Fig. 2A shows that the increase in S&E publications correlates positively with the increase in full-time R&D jobs from 1990–2004, in both Latin America (from 105 to 160 thousand jobs) and Spain (from 37.7 to 101 thousand jobs). Interestingly, from 1990–2000 the slopes of the curves shown in Fig. 2A show that the increase in S&E publications for a given increase in R&D jobs was proportionally higher in Latin America than in Spain. From 2001 to 2004, the curve for Latin America seems to parallel the curve for Spain. The possible reasons why the more vigorous growth in Latin American R&D jobs in the 1990s appears to have been dampened since 2001 remain to be better investigated.

Quite remarkably, Fig. 2A also shows that although similar numbers of S&E publications originated from Latin America and Spain in 2004, the number of R&D jobs in Latin America was 1.6-fold higher than in Spain in that same year. This suggests that, on average, the Latin American R&D system is considerably less effective than its Spanish counterpart in terms of generating new knowledge and publications from the existing work-force.

Somewhat surprisingly, the growth trend in S&E output in Latin America was not paralleled by increases in R&D spending regardless of whether GERD is calculated as a percentage of the GDP of each country or as total investment in US dollars (*8*). This brings about an effective decrease in the already low cost (per publication) of science in Latin America compared to developed countries (*5, 16*). It should also be

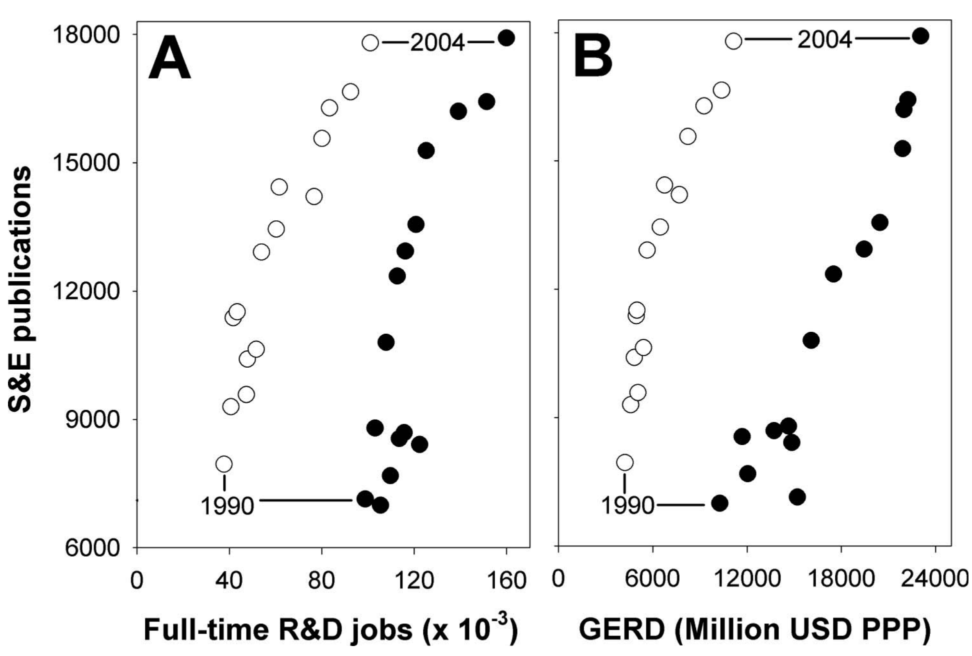

Figure 2. (A) Correlation between S&E publications (indexed in the Pascal database) and full-time R&D jobs in Latin America and in Spain (from 1990–2004). Data from RICYT (*10*). (B) S&E publications (indexed in the Pascal database) as a function of GERD (as Million USD PPP, from 1990 to 2004) in Latin America and Spain. Data from RICYT (*10*). Data for Spain are shown as open symbols and for Latin America are shown as closed symbols.

noted that in developed countries (e.g., Canada and USA) an opposite trend is observed, with increasing cost per published article in the past 10 – 15 years (*5, 16*). While at first glance this might lead to the conclusion that efficiency is improving in Latin American science, it may well be that this severe economic constraint explains the meager increases in international recognition of Latin science in recent years (see below). In other words, an issue that needs to be carefully examined is whether the decrease in average cost of Latin American science has been a barrier to improvements in the recognition of science produced in this region.

On the other hand, when spending in R&D is expressed as USD PPP, there was a significant increase in Latin American GERD from 1990 – 2004 (from 10.3 to 23 billion USD PPP; *10*), and this correlates with the increasing number of S&E publications (Fig. 2B). The same trend is observed for Spain. Direct correlations between GERD (expressed as USD PPP) and S&E publications was also observed for individual Latin American countries including Brazil ($r^2 = 0.93$), Mexico ($r^2 = 0.94$) and Chile ($r^2 = 0.79$; data not shown). Closer inspection of the data in Fig. 2B shows a roughly linear correlation between Latin American S&E output and GERD from 1990 – 2000. On the other hand, a tendency of increased slope of the curve is suggested by the data from 2001 – 2004, suggesting more efficient utilization of economic resources in the region in the past half decade. Whether this optimistic forecast will be confirmed in future years remains to be seen.

THE RECOGNITION OF SCIENCE

One important indicator for the evaluation of the quality and relevance of science is its impact or peer recognition, which can be measured by the average number of citations per paper (CpP) (*11*), a metric that may be used for comparative evaluation of individual or groups of researchers, research institutions, countries or continents. Other bibliometric indicators have been proposed, such as the recent H-index (*17, 18*) and the creativity index (*19*), but they have been used for comparisons between individuals or groups of researchers, and not for nations. We note in passing that there is currently extreme controversy in the scientometrics literature as to whether impact factors of the journals where articles are published can be taken to reflect in any meaningful way the true impact of individual articles (*20 – 25*). Therefore, we have not here considered journal impact factors in our analysis of recognition of S&E in Latin America and other regions.

The data presented in Table 2 and Fig. 3A show that the impact of science (expressed as CpP) is a function of GERD (as % of GDP) in selected developing and developed nations. A similar trend was recently shown (*5*) using a much smaller set of countries. Developing nations, including Brazil, Mexico and Argentina (the top-3 Latin American countries in terms of S&E output; Table 1) present lower GERDs (0.4 – 1.2%) and lower CpP ratios (2.9 – 5.2). Higher investments in R&D (above 1.5% of GDP) resulted in significantly increased recognition of science. A curious exception to this rule was South Korea, which invests 2.5% of its GDP in R&D and exhibits a CpP ratio of only 4.7 (Table 2). The case of South Korea is interesting because this country has been frequently used in recent years as an example of successful return of the investment in R&D in terms of technological development and industrial innovation (*26*); the country also presents the second fastest annual growth rate of GERD spending among OECD members (*2*). The data in Table 2 show that the return of that proportionally very high investment in R&D has not been nearly as impressive in terms of the average recognition of South Korean science. On the other hand, Ireland (the so-called Celtic tiger by economists), Italy, and Spain presented much lower GERD (as % of their GDPs) than South Korea and significantly higher recognition measured by CpP (Table 2). Collectively, these data suggest that investment of a higher percentage of the GDP in R&D is an important determinant but is not sufficient for achievement of high recognition of national science, reinforcing the notion that efficient and well-aimed spending in R&D is critical for qualitative improvement of science.

The curve presented in Fig. 3A also shows that the highest CpP ratios are achieved at GERD levels corresponding to >2% of GDP, indicating that Latin American countries should contemplate significant increases in their R&D investments, *as well as efficient spending*, in order to promote the visibility and recognition of their scientific output. A good example of a major current effort towards an increase in R&D spending is China, which is reported to have invested 36 billion USD in 2006 (equivalent to 136 billion USD PPP), 20% more than the expenditure in 2005. Moreover, the number of researchers in China increased 77% from 1995 to 2004, reaching a head-count of over 900,000 (*27*). These recent policies should result – in the near future – in significant increases in both the number of S&E publications and in the recognition of Chinese science (as CpP).

Fig. 3B shows that recognition of science also correlates with the overall wealth of nations, expressed as GDP per capita. Nations with GDP per capita lower than 15,000 – 16,000 USD (including the top-3 Latin American countries in terms of S&E output) presented the lowest levels of recognition of science (<6 CpP). Similar results are obtained if the wealth of nations is expressed as GDP per capita in USD PPP ($r^2 = 0.80$ for linear regression of data for 34 countries; data not shown).

Moreover, CpP is also a function of the number of researchers per million inhabitants (RpM). In general, countries with less than 2,000 RpM (including the top-3 Latin American countries) scored less than 6 CpP (Fig. 3C and Table 2). The nation with the highest RpM ratio, Finland (where over 20% of the employed population work in R&D; *2*), presented a CpP of 10.7, a high value even among the developed nations listed in Table 2. Interestingly, Israel and

Table 2
Socio-economic indicators, R&D investment and recognition of S&E publications of selected developed and developing nations

	HDI Rank (in 2003)[1]	GDP per capita (USD) in 2003[1]	GDP per capita (USD PPP) in 2003[1]	GERD (% GDP)[1]	RpM[1]	CpP
Selected developing nations						
Argentina	34	3,524	12,106	0.4	715	4.6[3]
Mexico	53	6,121	9,168	0.4	259	5.2[3]
Russia	62	3,018	9,230	1.2	3,415	3.4[2]
Brazil	63	2,788	7,790	1.0	324	4.7[2]
China	85	1,100	5,003	1.2	633	3.3[2]
South Africa	120	3,489	10,346	0.7	192	4.9[3]
India	127	564	2,892	0.8	120	3.5[2]
Selected developed nations						
Norway	1	48,412	37,670	1.7	4,442	9.8[3]
Iceland	2	36,377	31,243	3.1	6,592	11.6[2]
Australia	3	26,275	29,632	1.5	3,446	9.0[2]
Luxemburg	4	59,143	62,298	1.7	3,457	N.A.
Canada (G7)	5	27,079	30,677	1.9	3,487	10.6[2]
Sweden	6	33,676	26,750	4.3	5,171	11.3[2]
Switzerland[4]	7	43,553	30,552	2.6	3,594	13.6[2]
Ireland	8	38,487	37,738	1.1	2,315	8.6[2]
Belgium	9	29,096	28,335	2.2	3,180	10.1[2]
USA (G7)	10	37,648	37,562	2.7	4,526	12.9[2]
Japan (G7)	11	33,713	27,967	3.1	5,085	7.8[2]
Finland	13	31,058	27,619	3.5	7,431	10.7[2]
UK (G7)	15	30,253	27,147	1.9	2,691	11.2[2]
France (G7)	16	29,410	27,677	2.3	3,134	9.4[2]
Italy (G7)	18	25,471	27,119	1.1	1,156	9.0[2]
Germany (G7)	20	29,115	27,756	2.5	3,222	9.8[2]
Spain	21	20,404	22,391	1.0	2,036	7.5[2]
Israel	23	16,481	20,033	4.5	1,570	9.6[2]
South Korea	28	12,634	17,971	2.5	2,979	4.7[2]

[1]Values are from the HDI Report 2005 (http://hdr.undp.org/reports/global/2005/pdf/HDR05_HDI.pdf). RpM: researchers in R&D per million inhabitants (1990–2003; using the most recent available data). G7 nations are indicated. [2]From January 1995 to August 2005 (source: http://www.in-cites.com). [3]Mexico and S. Africa: 1992–2002; Argentina: 1994–2004; Norway: 1996–2006. [4]Second place in CpP rank among all countries in the world (CpP = 13.6 in 1995–2005, increasing to 14.1 in 1996-August 2006). N.A., Not available.

Italy presented high recognition of science (CpP = 9.0-9.6) with smaller RpM ratios (1,200–1,500 RpM), indicating highly efficient utilization of the S&E work-force. Conversely, Russia and South Korea presented lower recognition of science (CpP values comparable to those of the top 3 Latin American countries) and considerably higher RpM values (Table 2), suggesting that use of their large S&E workforce is not optimized to produce high-impact publications. In Korea, a large proportion of the R&D workforce (71–72%; *2*) is involved in industrial activities, therefore placing less effort in original S&E output.

Similar to the trend exhibited when CpP was analyzed as a function of GERD (Fig. 3A), CpP ratios for different countries asymptotically approach a plateau level at RpM values of 3,000 and larger (Fig. 3C). These observations suggest that if Latin American countries wish to see improvements in the recognition of their scientific output, they should devise effective policies to increase their RpM ratios, and, more importantly, to focus on the efficiency of the workforce in R&D. This could be achieved, for example, through better salaries and, even more importantly, through the establishment of differential salary policies aimed to explicitly reward creativity, productivity and discoveries. Latin American countries could follow examples such as those provided by the high efficiency of the Spanish or Italian R&D workforces (Figs. 2A and 3C).

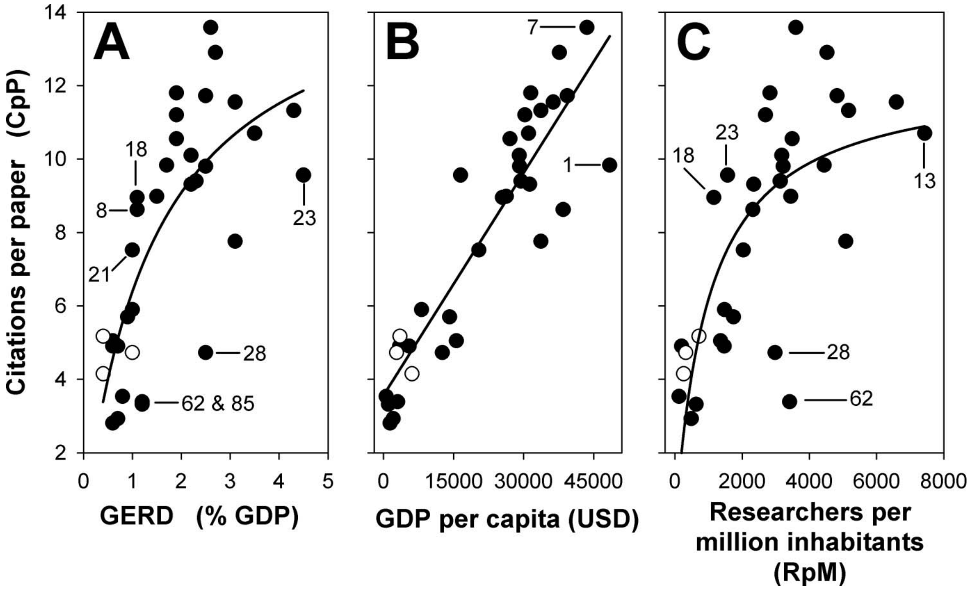

Figure 3. (A) Average number of citations per paper (CpP) as a function of GERD (expressed as percentage of GDP) in 34 developed and developing countries. The countries and corresponding HDI ranks (in parenthesis) are: Norway (1), Iceland (2), Australia (3), Canada (5), Sweden (6), Switzerland (7), Ireland (8), Belgium (9), United States (10), Japan (11), The Netherlands (12), Finland (13), Denmark (14), United Kingdom (15), France (16), Austria (17), Italy (18), Germany (20), Spain (21), Israel (23), Greece (24), Portugal (27), South Korea (28), Argentina (34), Hungary (35), Poland (36), Mexico (53), Russia (62), Brazil (63), China (85), Iran (99), South Africa (120), Morocco (124) and India (127). Selected countries are identified in the figure by the HDI-rank. Brazil, Mexico and Argentina are shown as open circles. The solid line represents a fit of a rectangular hyperbole to the data. GERD values (1997–2002) are from the 2005 HDI Report (http://hdr.undp.org/reports/global/2005/pdf/HFR05_HDI.pdf - see p. 262), except for Israel, Iran and Morocco, for which data are from the UNESCO database (http://www.uis.unesco.org/profiles/selectCountry_en.aspx). Values for CpP (for a 10-year period) are from the In-Cites database (http://www.in-cites.com), and the most recent available 10-year period was used for each country – in most cases from 1995–2005. (B) Correlation between CpP ratios and GDP per capita (expressed in 2003 USD equivalents) for 34 nations (the same as in panel A). GDP per capita was from the 2005 HDI report. Data points for Brazil, Mexico and Argentina are shown as open circles. The solid line represents a linear fit to the data ($r^2 = 0.827$). (C) CpP ratios as a function of the number of researchers per million inhabitants (RpM) for 33 nations (the same as in panel A, excluding Morocco). RpM data (1990–2002) are from the 2005 HDI report, and refer to the most recent available data. Data points for Brazil, Mexico and Argentina are shown as open circles. The solid line represents a fit of a rectangular hyperbole to the data.

It is also informative to compare the evolution of the citation rates of publications from different nations over the past few years. Fig. 4A shows the increase in CpP calculated at overlapping 5-year intervals (from 1992–2004) in selected developed and developing countries. For all countries, linear regressions yielded excellent fits to the data (r^2 ranging from 0.93–0.99), indicating a universal trend for a linear increase in citation rates as a function of time. Interestingly, however, CpP is not increasing at the same rate for all countries. Brazil and Mexico, for example, showed ΔCpP/year values of 0.04 and 0.05, respectively (Fig. 4B). This is about 3-fold lower than the rates of CpP increase exhibited by Spain, Australia and Germany (ΔCpP/year values 0.14, 0.15 and 0.14, respectively). In the context of Latin America, Argentina is doing somewhat better than the other countries, with a ΔCpP/year value of 0.10, the same growth rate shown by South Africa and Italy. Therefore, the trends depicted in Fig. 4 show that, in addition to the large absolute difference in present CpP values between developed and developing nations, their rates of growth during the past 10–15 years are also markedly different. Rather than catching up with the more scientifically developed nations (such as Germany), Latin American nations are on a track that foretells even greater future divergence between the recognition of science produced in developed nations and in Latin America. Governments in the region should take these trends into account when assessing results of current scientific policies and planning future actions.

PUBLICATION AND RECOGNITION IN BMB AND IN THE BIOMEDICAL SCIENCES

Table 3 shows total publication and average CpP values in different research sub-areas within the biomedical sciences for five selected developed countries and six selected developing

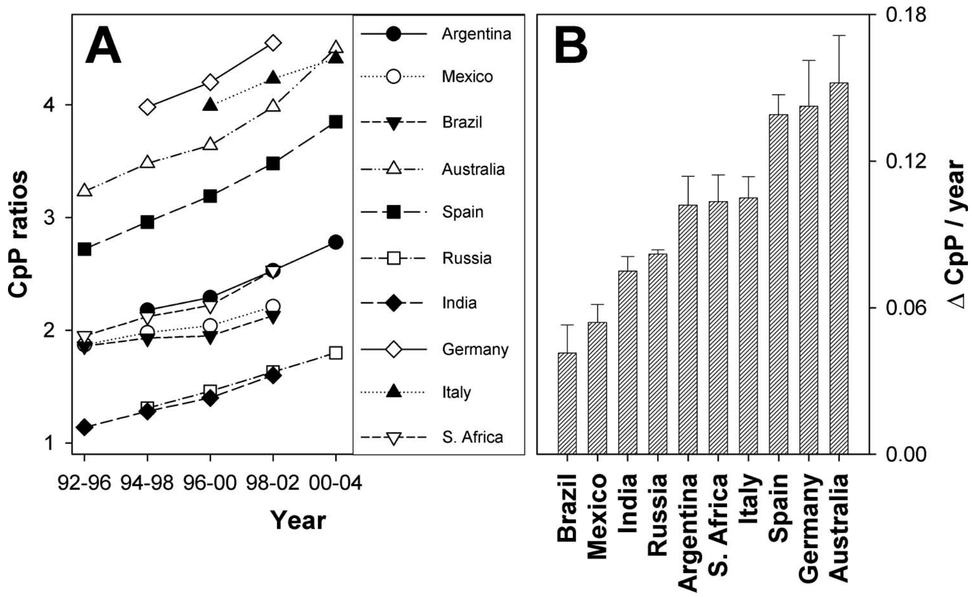

Figure 4. (A) Evolution of average CpP ratios for selected developed and developing countries (including the top 3 S&E producing Latin American nations). Values for CpP were obtained from the In-Cites database. (B) Slopes of the curves shown in panel A (ΔCpP/year, obtained by linear regression analysis of the data).

nations, including Brazil, Mexico and Argentina. In the five developed countries analyzed, 'molecular biology and genetics' exhibited the highest CpP values, followed by 'biology and biochemistry' and immunology (Table 3). In developing countries, the highest citation ratios were found for publications in the fields of immunology or 'neuroscience and behavior'. Nonetheless, for both developed and developing countries, the sub-areas of 'biology and biochemistry' and 'molecular biology and genetics' compared favorably to the other research areas in terms of CpP.

Rather than comparing citations of publications across different research areas, however, we feel that it is more informative to compare citations between developed and developing countries within the same research areas. For all areas listed in Table 4 (including physics, chemistry, medicine and biomedical sciences), the so-called G7 countries presented significantly (1.8- to 3.5-fold) higher CpP values than the 3 largest economies of Latin America (LatAm-3 group = Brazil, Mexico and Argentina). Of particular interest here, in the sub-areas of 'molecular biology and genetics' and 'biology and biochemistry', the differences in CpP values between developed and developing countries were the largest, with publications originating from G7 nations harvesting, on average, 2.9- to 3.5-fold more citations in the scientific literature than publications originating from LatAm-3 countries. Research intensity (see definition in the legend to Table 4), however, was not different when comparing these two sub-areas in G7 and LatAm-3 nations (Table 4). Moreover, the fields of 'molecular biology and genetics', 'biology and biochemistry' and medicine average 23.8, 13.2 and 13.3 CpP, respectively, in four Nordic countries (Finland, Sweden, Iceland and Denmark; data not shown). Therefore, CpP values from LatAm-3 nations also fall far behind those from nations that are not the largest world economies but are 'gold standards' in terms of global socio-economic development indexes.

In addition, the relative citation output of Latin American science in general is also lower than world averages in different areas. For BMB in particular, the relative citations acquired by publications from LatAm-3 nations plus Chile and Venezuela in 1997–2001 were 6–31% lower than world averages in that period (Table 5; *9*). Importantly, Table 5 also shows – as a general trend – a very modest growth in relative citation output of Latin American science in the 1990s and early 21st century. This is in sharp contrast with the exuberant regional growth in absolute number of publications and in world share of publications discussed above, and highlights the urgent need to develop strategies aimed at increasing the visibility and recognition of Latin American S&E as opposed to simple quantitative increases in S&E output (i.e., number of publications) from the region.

CONCLUDING REMARKS

In the past two decades, Latin America as a whole maintained a growth rate of its scientific output that was significantly larger than that exhibited by most of other geopolitical regions of the world. As a result, the world share of scientific publications originating from Latin America

Table 3

CpP values and total number of publications in different sub-areas within the biomedical sciences for selected developed and developing nations

	Biology & Biochemistry	Molecular Biol. & Genetics	Pharmacology & Toxicology	Immunology	Neuroscience & Behavior
Developed countries					
USA	21.60*	32.90	12.70	24.81	21.45
(1995–2005)	200,112**	111,492	45,716	51,675	114,359
Australia	14.06	22.04	10.06	19.16	14.18
(1995–2006)	14,124	6,164	3,552	4,373	6,524
Canada	16.57	24.82	11.40	20.35	17.30
(1994–2004)	25,511	12,934	5,966	4,983	16,850
Italy	10.28	17.61	8.36	17.17	11.46
(1995–2005)	21,450	9,817	7,257	5,509	15,164
Spain	9.83	16.17	6.33	12.31	11.51
(1994–2004)	14,179	6,094	4,275	2,786	7,285
Developing countries					
Argentina	5.69	6.34	4.85	7.28	9.68
(1994–2004)	3,650	1,333	759	599	1,247
Mexico	4.61	9.13	4.88	8.88	8.56
(1992–2002)	2,459	773	694	381	1,146
Brazil	4.87	5.48	4.96	10.21	5.34
(1992–2002)	5,455	2,527	1,814	1,169	2,944
Russia	5.93	5.37	6.33	8.95	5.51
(1994–2004)	11,889	6,394	585	481	2,436
South Africa	7.29	13.44	4.90	10.39	6.90
(1992–2002)	1,725	621	504	394	312
India	3.85	5.95	2.87	7.12	3.57
(1992–2002)	9,847	2,163	2,963	1,016	1,715

*Average CpP ratio in the period indicated. **Total number of publications (ISI/WoK database) in the indicated period. The distribution in different research fields follows the classification of the ISI/WoK database. Source: http://www.in-cites.com/countries/2006menu.html

Table 4

Average CpP values and research intensities in G7 and LatAm-3 nations

	LatAm-3 ($n = 3$)	G7 countries ($n = 7$)	CpP Ratio[3] (G7/LatAm3)
Biological Sciences			
Biology & Biochemistry	5.1 ± 0.6 (7.4 ± 1.4%)[1]	15.2 ± 3.9 (7.1 ± 0.7%)[1]	2.9
Molecular Biol. & Genetics	7.0 ± 1.9 (2.8 ± 0.7%)	24.3 ± 5.8 (3.5 ± 0.4%)	3.5
Pharmacology & Toxicology	4.9 ± 0.1	10.0 ± 2.7	2.0
Immunology	8.8 ± 1.5	19.1 ± 3.1	2.2
Neuroscience & Behavior	7.9 ± 2.3	15.8 ± 3.9	2.0
Microbiology	6.8 ± 2.2	14.0 ± 3.6	2.1
Medicine[2]	5.7 ± 1.5 (13.9 ± 1.4%)	10.8 ± 2.7 (22.2 ± 2.0%)	1.9
Physics	4.7 ± 1.0 (15.7 ± 1.9%)	8.5 ± 1.6 (11.1 ± 3.7%)	1.8
Chemistry	4.1 ± 0.3 (11.8 ± 2.3%)	9.3 ± 2.0 (11.2 ± 3.1%)	2.3

Data from http://www.in-cites.com/countries/2006menu.html. [1]Numbers between brackets represent research intensity, expressed as percent share of publications in one sub-area relative to the total number of publications in all areas (in ISI/WoK database) of LatAm-3 (top three S&E producing countries in Latin America: Argentina, Mexico and Brazil) and G7 nations (USA, Canada, UK, France, Germany, Italy, Japan). [2]Classified in ISI/WoK as ‘clinical medicine’, which includes surgery and excludes psychiatry. [3]CpP ratios were calculated (in each area) dividing the average CpP values for G7 countries by the average CpP values for LatAm-3 countries in different areas.

Table 5
Evolution of relative citation output from selected Latin American countries – comparison between 1991–1995 and 1997–2001

	Brazil	Mexico	Argentina	Chile	Venezuela
BIOL	0.81 → 0.88	0.81 → 0.81	0.75 → 0.81	0.84 → 0.88	0.81 → 0.81
BIOS	0.75 → 0.75	0.69 → 0.75	0.81 → 0.81	0.94 → 0.94	0.88 → 0.69
BIOM	0.81 → 0.81	0.81 → 0.88	0.56 → 0.75	0.69 → 0.94	0.75 → 0.75
CLI1	0.78 → 0.94	0.81 → 0.88	0.63 → 0.81	1.19 → 1.19	0.81 → 0.84
CLI2	0.83 → 0.83	1.00 → 1.00	0.91 → 1.03	0.88 → 1.19	0.84 → 0.97
PHYS	0.81 → 0.81	0.81 → 0.81	0.81 → 0.88	0.80 → 0.66	0.66 → 0.79
CHEM	0.81 → 0.95	0.81 → 0.81	0.75 → 0.81	0.66 → 0.83	0.80 → 0.77

Data from Glanzel et al. (*9*). The different scientific areas analyzed are (according to Glazel and coworkers; *9*): BIOL = Biology (Organismic & Supraorganismic Level); BIOS = Biosciences (General, Cellular & Subcellular Biology; Genetics); BIOM = Biomedical Research; CLI1 = Clinical and Experimental Medicine I (General & Internal Medicine); CLI2 = Clinical and Experimental Medicine II (Non-Internal Medicine Specialties); CHEM = Chemistry; PHYS = Physics. Citations in the field of BMB are distributed between BIOS and BIOM.

Table 6
Comparison between selected countries presenting GERD close to 1% of their GDPs

Country	GDP in 2003 (billion USD or billion PPP USD)	GERD (% GDP)	GERD[1] (billion USD or billion PPP USD)	CpP (10-year period)[3]	Publications (10-year period)[3]
Ireland	154 (151 PPP)	1.2%[2]	1.7 (1.7 PPP)	8.62	29,928
Italy	1,468 (1,563 PPP)	1.1%	16.1 (17.2 PPP)	9.38	358,452
Spain	839 (920 PPP)	1.0%	8.4 (9.2 PPP)	8.01	254,808
Brazil	492 (1,376 PPP)	1.0%	4.9 (13.8 PPP)	4.81	119,676

[1]Estimated from values of GDP and GERD (HDI Report 2005; see legend to Table 2). [2]GERD as a % of GDP is currently closer to 1.2% (see ref. *29*). [3]Publications are those indexed in ISI/WoK in a 10-year period (Ireland = January 1995 to October 2005; Brazil = January 1996 to April 2006; Italy and Spain = January 1996 to August 2006); CpP are from the same period (CpP values for Brazil, Spain and Italy are updated relative to those shown in Table 2); data are from the In-Cites database.

increased considerably in that period. These auspicious results may likely be attributed to a large increase in the number of doctoral degrees awarded per year in the region and to increasing governmental investments in R&D (as USD PPP). Despite this clear quantitative development, however, the relative impact of Latin American science is still lower than world averages in most research areas (for example, in BMB) and has only shown a modest improvement in the past decade. We conclude, therefore, that despite robust quantitative growth, qualitative improvement of Latin American S&E has not been nearly as impressive. To further illustrate this point, we note that King (*1*) showed that among the 1% most cited papers in the world in 1997–2001, only 188 out of 38,263 (representing 0.5% of those papers) were from Latin America; by comparison, Spanish publications represented 2.1% of that list.

For a number of developed and developing nations, we show that recognition of S&E output in terms of citations to published works correlates with the overall wealth of the nations (GDP per capita), with the number of jobs in R&D and, importantly, with national investment in R&D (expressed as a % of GDP). Therefore, if Latin American countries wish to increase the visibility and impact of their scientific output, they should, at the same time, maintain the current focus on the qualification of S&E human resources (through the continued development of their higher education and post-graduate training systems) and increase their spending in R&D to percentages of GDP more comparable to those practiced by developed nations. In practice, this would mean raising current GERD levels from ≤1% of GDP to about 2% of the GDP. We realize that this is not a goal that can be readily achieved; rather, it should be viewed as a medium-term goal to be included with high priority in national planning strategies.

In more immediate terms, however, there may be alternative ways to more efficiently utilize some of the resources currently allocated to R&D in Latin American countries. As shown in Table 6, Ireland, Spain (countries of recent development (*28–30*) – 8th and 21st in the HDI rank in 2003, respectively) and Italy (a G7 nation; 18th in the HDI rank), invest only 1.0–1.2% of their GDP in R&D and have high S&E output – as numbers of publications – and high science recognition (as CpP). Comparison between the performances of Ireland and Brazil is particularly interesting: while the GDP and GERD of Brazil are about 3-fold higher than the values for Ireland (and the number of Brazilian publications is ~4-fold higher than Irish publications), the recognition of Brazilian science (measured by CpP) is approximately half of the recognition of Irish science. These examples indicate that better utilization of currently available R&D resources by Latin American nations (including more efficient governance) might lead to significant improvements in the recognition and quality of science produced in the region. In this regard, we note that intense investments in education (from pre to post-graduate levels) have been a key issue for the recent Irish development and spectacular economic growth (*29, 30*). This is another example to be followed by Latin American nations.

Collectively, the data presented in this article suggest that governmental agencies involved in funding S&E activities in Latin America should pay close and immediate attention to the general procedures utilized for evaluation of grant proposals and project reports. Unfortunately, rather than prioritizing more qualitative forms of evaluation of the productivity of scientists and projects, several of those agencies appear to be giving undue emphasis to quantitative evaluation of the numbers of publications by individual scientists. This, in turn, generates increased pressure on the scientific community to publish as many articles as possible, likely at the expense of publishing more complete or innovative works that could have higher impact in the scientific literature. Indeed, the pressure to publish more and more, frequently under inadequate conditions of funding and infra-structure, has been recently pointed out as a cause of anxiety, desperation and burn-out for Brazilian scientists in the field of BMB (*31, 32*).

Nevertheless, we feel that the results presented here are also reason for optimism for the development of S&E in general, and of the natural sciences (including BMB) in particular, in Latin America. Undoubtedly, any investment in S&E would be lost if qualified human resources were not available to use them. In this regard, the recent evolution in S&E doctoral degrees and in the number of S&E jobs in the region form an essential basis on which to build future policies aimed at the qualitative development of Latin American science. Several areas of BMB and of the biomedical sciences have shown significant qualitative growth in recent years or represent relatively consolidated areas in Latin America. These include, among others, comparative biochemistry and physiology, ion transport, oxidative stress and free radical biology, neurobiology, plant biochemistry and, more recently, structural biology and genomic/proteomic analysis of organisms and biomolecular processes. Moreover, South-South collaborations among Latin American countries (in particular between Brazil and Argentina and between Brazil and Chile) have been increasing and becoming as relevant as the so-called South-North collaborations in helping to increase the recognition of science in the region (*9, 11*). Given that the most important factor, namely the existence of highly qualified human resources, is in place, we feel that Latin America is well poised to improve the visibility of its science by reshaping R&D policies in the region to prioritize qualitative growth.

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