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The cost of Latin American science
Introduction for the second issue of CBP-Latin America

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Abstract

Latin American researchers in science and engineering (S&E), including those in biology and biomedical sciences, are frequently exposed to unstable conditions of financial support, material and human resources, and a limited number of positions at public and private institutions. Such uncertainties impose continuous challenges for the scientific community which, in the best of cases, responds with careful planning and creativity, and in the worst scenario endures the migration of scientists to the USA or Europe. Still, the number of scientific publications from Latin American institutions in the last decade increased at a much faster rate than publications from the USA and Canada. A brief analysis per country of the gross domestic product (GDP) spent in research and development (R&D) and the S&E production reported by the Pascal bibliographic database suggests that the number and quality of S&E publications is directly proportional to the financial support for R&D. However, the investment in R&D in Latin America did not increase at the same rate (from 0.49 to 0.55% of GDP, from 1990 to 2003) at which S&E publications did in the same period (2.9-fold increase, from 1988 to 2001). In Latin America, the traditional financial support for scientific research continues to be from federal and state government funds, associated in some cases with institutional funds that are mostly directed towards administrative costs and infrastructure maintenance. The aim of this introduction is to briefly discuss the production cost of articles published in refereed S&E journals, including the cost of the scientific research behind them, and, at the same time, to increase the awareness of the high quality of scientific research in Latin American institutions despite the many challenges, especially financial constraints, faced by their scientists. The second issue of Comparative Biochemistry and Physiology dedicated to Latin America ("The Face of Latin American Comparative Biochemistry and Physiology") celebrates, by means of 26 manuscripts from five countries, the diversity and quality of biological science in the continent.

Keywords: Latin America; Science and technology; Cost of scientific research

1. Investment in science and technology in Latin America

Science has become an issue of increasing public awareness in Latin America in the last decade. An increase, albeit small, in the investment in scientific research and development (R&D) occurred in Brazil, Chile and Mexico within the past 10–12 years (Pinheiro-Machado and Oliveira, 2001; RICYT, 2003, 2004; UIS Report, 2005). In Latin American and Caribbean countries R&D expenditure is approximately 0.1% to 1.0% of the gross domestic product (GDP), a relatively small investment compared with Canada, the USA, Japan or Europe, where the investment is typically 2–3% of their GDP (Tables 1 and 2) (Kawha and Ramkissoon, 2005; UIS Report, 2005; Hermes-Lima and Navas, 2006). It is not difficult to visualize a cumulative deficit in R&D expenditure between Latin America and Canada or the USA through time. While the investment in R&D has only increased modestly in Latin American countries

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Table 1
Key indicators of world gross domestic product (GDP), population and gross domestic expenditure on research and development (GERD) during 2002

	GDP (in billions)	% world GDP	Population (in millions)	% world population	GERD (in billions)	% world GERD	% GERD/GDP	GERD per inhabitant
Developed countries	28,257	59.4	1195.1	19.3	645.8	77.8	2.3	540.4
Developing countries	18,607	39.1	4294.2	69.5	183.6	22.1	1.0	42.8
Less-developed countries	736.4	1.5	686.9	11.1	0.5	0.1	0.1	0.7
Americas	14,949	31.4	849.7	13.8	328.8	39.6	2.2	387.0
North America	11,322	23.8	319.8	5.2	307.2	37.0	2.7	960.5
Latin America and the Caribbean	3628	7.6	530.0	8.6	21.7	2.6	0.6	40.9
Europe	13,286	27.9	795.0	12.9	226.2	27.3	1.7	284.6
Argentina	387	0.8	36.5	0.6	1.6	0.2	0.4	44.0
Brazil[a]	1300	2.7	174.5	2.8	13.1	1.6	1.0	75.0
Japan	3481	7.3	127.2	0.1	106.4	12.8	3.1	836.6
México	887	1.9	100.8	1.6	3.5	0.4	0.4	34.7
United States of America	10,414	21.9	288.4	4.7	290.1	35.0	2.8	1005.9

Modified from source: UNESCO Institute for Statistics estimations, December 2004, www.uis.unesco.org/TEMPLATE/pdf/S&T/WdScienceRepTable1.pdf.
[a] GERD value for Brazil is from 2000; GDP and GERD are shown in US dollars.

(Table 2), the number of scientific publications in Latin America increased at a much faster rate in the last decade than publications from the USA and Canada (Holmgren and Schnitzer, 2004; Hermes-Lima and Navas, 2006).

The correlation between R&D invested (in millions of USD) by Latin American countries and their number of science and engineering (S&E) publications recorded in Pascal in 2003 suggests that a country's scientific production is directly proportional to its expenditure in R&D (Fig. 1; when data are analysed as % GDP spent in R&D, the correlation is also valid: $r=0.761$; $P<0.05$, $n=17$ countries). A similar correlation was done by King (2004); however, it involved mostly developed nations. Similarly, the number of researchers (per million inhabitants) of Latin American nations correlates with spending in R&D ($r=0.564$; $P<0.05$, $n=17$ countries; see also Hermes-Lima and Navas, 2006). Furthermore, the proportion of GDP invested in R&D by several developed and developing countries correlates significantly with the number of citations per S&E paper (Fig. 2). It is noteworthy that G7 countries had 5.5 to 8.5 citations per paper (between 1997 and 2002) while Brazil had only 3.5. These data suggest that increasing a country's expenditure in R&D would result in a proportional increase in its researcher population, its output in S&E publications and, assuming that the number of citations a paper receives is a reflection of its relevance/impact (see: Pellegrini Filho et al., 1997), in the scientific quality of those publications.

Table 2
Evolution of investiment in R&D as a percentage of GDP in Latin America and Caribbean (LAC) and four selected countries

	LAC	Brazil	Mexico	Chile	Argentina
1990–1991	0.49%	0.82%	n.a.	0.52%	0.33%
1992–1993	0.46%	0.83%	0.22% (1993)	0.60%	0.40%
1994–1995	0.57%	0.90%	0.30%	0.62%	0.46%
1996–1997	0.53%	0.77% (1996)	0.33%	0.51%	0.50%
1998–1999	0.57%	n.a	0.40%	0.50%	0.51%
2000–2001	0.55%	1.00%	0.38%	0.53%	0.49%
2002–2003	0.55%	0.96%	0.40% (2002)	0.65%	0.45%

Values are average of 2 years, except when indicated. For comparative purposes, the percentage of GDP spent in R&D by Canada grew from 1.5% (1990) to 1.9% (2003). Data taken from RICYT, 2004. n.a.: Data not available.

From the data shown in Figs. 1 and 2, it is possible to calculate the cost of producing a scientific publication in Latin American countries relative to the proportion of their GDP directed to S&E. Resulting estimates vary from 140,000 to 750,000 USD per S&E paper ($n=16$ countries). These figures are significantly lower when compared with Canada (1.4 million USD per paper) and the USA (1.8 million USD per paper). These observations may suggest that scientific research is less expensive in Latin American countries. However, there are other costs involved in producing a scientific paper that might underline this inequality. It is commonly assumed, and generally true, that salaries and overhead charges are lower, while the costs of reagents, materials and scientific equipment, as well as costs of traveling to meetings, conferences and training fellowships are higher in Latin America than in the USA and Canada. The question then becomes, what is the real cost of scientific research in Latin America?

2. The cost of scientific research in Latin America

In order to compare the cost of scientific research in Latin America, Canada and the USA, we surveyed prices of basic reagents, materials and equipment commonly used by biochemists and physiologists. As an example, Table 3 shows a comparison of the costs of glucose, cryovials and a microcentrifuge obtained from catalogues, supplier listings, quotes from suppliers and distributors or receipts from recent purchases. These results briefly estimate that, on average, Latin American researchers pay 3.1 times more on reagents, 1.9 times more on materials and 1.5 times more on equipment than our counterparts in the USA. It is interesting to note that, even within the same country, prices can be highly variable depending on the region and the proximity to major cities. These differences in cost are caused by the location of the larger manufacturers and suppliers of materials, reagents and scientific equipment in the USA and Europe. Smaller manufacturers have started to appear in some Latin American regions (for example,

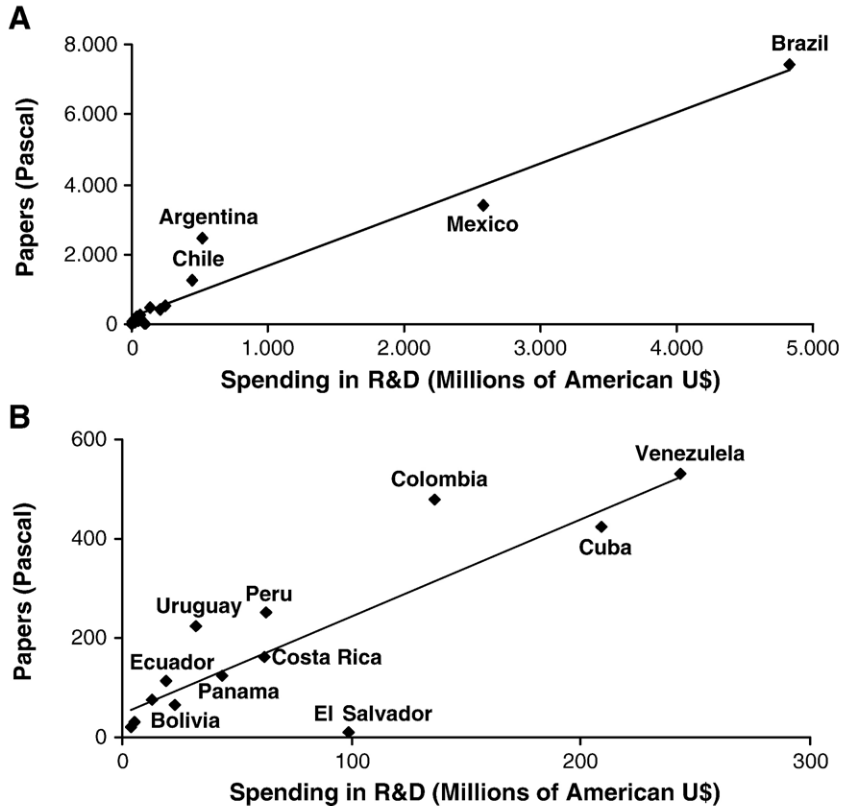

Fig. 1. A. Correlation between the expenditure in research and development (investment in R&D in 2002–2003, in millions of US dollars) by 17 Latin American countries (values for Colombia, Costa Rica and El Salvador are from 2001, 2000 and 1998, respectively) and their number of scientific publications as reported by the Pascal bibliographical database in 2003. Data from: UIS Report, 2005; The Human Development Report, 2005; RICYT, 2003, 2004. Correlation: $r=0.974$, $P<0.01$, $n=17$. Fig. 1A shows data from the four Latin American countries with the largest investment in R&D. B. (a magnification of a portion of Fig. 1A) shows data from 13 countries with less investment in R&D; points without indication of country name are Trinidad and Tobago, Paraguay and Honduras (13, 5.4 and 3.5 millions of US dollars spent in R&D, respectively). Just for comparison, Canada spent 16.6 billion US dollars in R&D in 2003 and published 22,862 papers in the same year.

São Paulo and Mexico City), offering similar products at competitive costs, providing an alternative for materials such as solvents, inorganic salts and glass- and plastic-ware. In most cases such smaller manufacturers still do not have the capacity to offer reagents of the high grade and purity needed for physiological and biochemical research, which can jeopardize the basic premise of scientific research of standardizing the assay conditions to make results comparable.

Considering the fact that these major manufacturers are located in the USA, Europe and Japan, added costs, not considered in the prices discussed previously, should be taken into account. Transporting goods from overseas necessarily increases shipping and handling costs and adds importing taxes, and often customs fees. The transport of reagents across longer distances requires that adequate storage conditions are provided, particularly for reagents and kits that have a short shelf-life and for items that need to be refrigerated or frozen. In addition, the international terrorism-related events over the past few years have yielded stricter regulations at customs and check-points across international borders, particularly on what are now considered dangerous goods or controlled substances. Such regulations often result in further costs and delays, and in stricter limits (including outright prohibitions) on importing certain reagents or kits. For all the previous reasons, it is not uncommon to receive reagents that are close to or past their due date or that have been thawed en route, forcing researchers to either purchase the goods all over again, or to request the suppliers to at least share the replacement costs. It is no wonder then that suppliers are reluctant to ship internationally and/or that they waive responsibility of the state of the goods upon delivery at their final destination. In addition to the financial cost, all of these transport issues result in a large investment in terms of the time needed for scientific research products to be delivered at the final destination. The time-lag between placement of a purchase order and receiving the goods can be as long as 3 months for reagents such as glucose, up to a year for centrifuges or microscopes and even longer for more specialized state-of-the-art equipment.

3. Funding of scientific research in Latin America

Economic growth in Latin American countries during the last decade of the 20th century was reflected as increases in S&E investment (Pinheiro-Machado and Oliveira, 2001). Table 4 shows the average annual funding per project that federal agencies allow in selected Latin American countries compared with USA and Canada. Projects in Latin America receive, on average, 75% less money than projects in Canada or the USA. In these countries, it is not uncommon for an individual laboratory

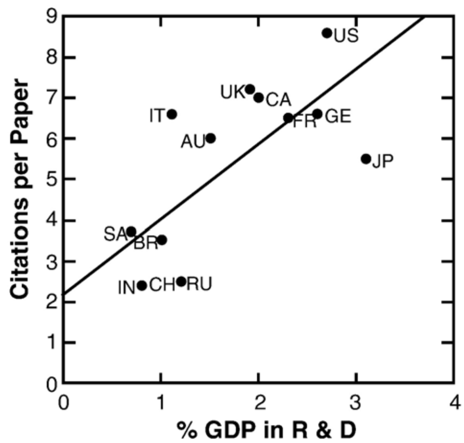

Fig. 2. Proportion of the gross domestic product invested in research and development (as percent of GDP spent in R&D (GERD)) by several nations correlates with the number of citations per paper (citations from 1997 to 2002 of papers from 1997 to 2001). Values of GERD are from 2002–2003, unless a different year is shown. Original data were taken from King (2004), UIS Report (2005), The Human Development Report (2005), however the present correlation has not been shown before. AU = Australia (GERD from 2000); BR = Brazil (GERD from 2000); CA = Canada; CH = China; FR = France; GE = Germany; IN = India (GERD from 2000); IT = Italy (GERD from 2001); JP = Japan; RU = Russia; SA = South Africa; UK = United Kingdom; US = United States of America. Correlation: $r = 0.724$, $P < 0.05$, $n = 13$.

to be the recipient of a 2 million USD research grant, while in Latin America similar funding can be assigned only to research projects involving a group of outstanding researchers from several laboratories and often from 3 or more institutions. These types of projects involve less than 2–3% of the country's researchers, which gives an indication of the low accessibility to large grants in Latin America. The average time elapsed between proposal submission and delivery of the funds is about 6 to 12 months. Furthermore, the number of sources that researchers have access to as options to finance scientific projects are far fewer than those available for researchers working in North America and Europe.

Table 3
Averaged estimate of reagents and materials costs commonly used in research in biochemistry and physiology in selected Latin American countries as compared to the USA and Canada

	10 mg glucose (99.5% purity)	50 cryovials	Microcentrifuge
Argentina	18.10 (3)	25.52 (3)	1435.00 (2)
Chile	19.04 (1)	28.33 (1)	2561.00 (1)
Costa Rica	70.98 (1)	30.79 (1)	1561.00 (1)
Mexico	16.78 (3)	44.16 (2)	1642.00 (2)
Uruguay	22.70 (1)	25.00 (1)	1340.00 (1)
Canada	8.96 (1)	24.49 (1)	1566.00 (1)
USA	6.20 (1)	16.44 (1)	1175.00 (1)

Prices shown are the averaged estimates calculated from information provided by researchers (n value in parenthesis) in the Americas (information was obtained from catalogues, supplier listings, quotes from suppliers and distributors or receipts from recent purchases). All prices are shown in US dollars and do not include shipping and handling, taxes, or other fees. Averages and SEM (in US dollars) for Latin America were: 19.16 ± 1.27 ($n = 4$ countries; Costa Rica was not considered), 30.76 ± 3.51 ($n = 5$ countries) and $1{,}708 \pm 220$ ($n = 5$ countries) for glucose, cryovials and microcentrifuge, respectively.

Table 4
Annual funding allotted per project by federal agencies in selected Latin American countries as compared to the USA and Canada

	Annual funding per project
Argentina	10,000–30,000
Brazil[a]	5000–100,000
Mexico	10,000–50,000
Canada	100,000–1,500,000
USA	150,000–2,000,000

Funds are shown in US dollars. Information was provided by researchers in the Americas, based on their own projects funded by their respective granting agencies in each country.
[a] Grants from FAPESP, an agency only researchers working at the State of São Paulo have access to, range from 10,000 to 300,000 US dollars per year.

Universities and research institutions have recently allotted growing efforts to commercialize their research royalties; however, the expansion of the intellectual property network is still uncertain in Latin American countries when compared to developed countries or even in rapidly developing countries, such as South Korea and China (World Intellectual Property Organization (WIPO)-Patent Cooperation Treaty (PCT)). This may be explained, at least in part, by cultural aspects and the bureaucratic processes involved in national or international patent regulations and laws (Oliveira and Pinheiro-Machado, 2004). According to the World Intellectual Property Organization (WIPO-PCT database), the USA had the highest number of patents with 35.7% of the world patent deposits in 2003, followed by Japan (15.2%) and Germany (12.7%). These are large values compared to South Korea (2.7%), China (1.1%), Brazil (0.2%) and Mexico (0.1%). The current trend in favor of biotechnological applications, which has spread into Latin America, represents a strategic opportunity to increase the number of patents. Although some preliminary progress has been achieved, more intensive forums of public policies involving researchers, governmental authorities and private corporations are required in order to maximize this possibility. Such political initiatives should have a positive impact on local science, as well as Latin America's social and economic development (Souza, 2004) (for the social role of the gene revolution in Brazil see: De Castro, 2004).

The increasing number of non-governmental organizations (NGOs) that have sprung-up world-wide might appear to provide additional funding options; however, these, as well as international foundations, preferentially finance research in areas such as ecology and social studies. These organizations seldom support research in biochemistry or physiology, and frequently their efforts are associated to specific fields with high social and epidemiological impact. NGOs' continuous activities have been of value to aim strategic research related to public health and to enhance claims toward governmental inputs on several public fields, including R&D (ABONG, 2006). Alternatively, research at academic institutions could be powered by funds from private corporations and foundations. In the past 5–10 years, Latin American governments have developed strategies to motivate private industries to invest in their country's science; for example, Brazil created a law in 1993, modified in 1997, to encourage private expenditure in S&E (Pinheiro-Machado and Oliveira, 2001). However, the added costs, in terms of expenditures and time-lag discussed previously, present Latin American countries as high-risk investments in terms of scientific projects. Perhaps as private industries and transnational companies become aware of the novel models used in biochemistry and physiology research, such as those presented in this special volume, they will become increasingly interested in funding research in Latin America.

4. Final remarks

This editorial is underlined by an apparent contradiction. While expenditures in R&D in Latin American countries is small and has barely increased in the past 10 years (Table 2), the number of S&E publications produced increased disproportionately in the same period (Hermes-Lima and Navas, 2006), suggesting that the cost of scientific research in Latin America is lower than in the USA and Canada. On one hand, smaller grants and lower salaries available in universities and research institutions in Latin America support the notion that scientific research would be more cost-effective in the less developed countries in Latin America. On the other hand, the elevated costs of materials, reagents and scientific equipment, increased by additional costs of transport, import taxes and other fees, shows that scientific research is more expensive in Latin America (it would be expected that any given country while implementing laboratories and research centers, acquiring infrastructure and equipment, should have a higher production cost per paper; after a time, the costs should decrease). While grants in the USA typically cover a significant portion of the researchers' salaries, in most Latin American countries salaries are not included in the R&D accounting, contributing to the false impression that science in Latin America is less expensive. Perhaps the collaborative nature of research in Latin America, often represented by more than one country, may have artificially increased the number of scientific publications in the late 1990's. Alternatively, the lower rate of increase in the number of scientific publications and the higher cost of producing them in the more developed countries reflects the more expensive nature of scientific research in areas such as molecular biology, where the use of top-of-the-line technology is required; something which is not generally available to researchers in Latin America because of the extremely high costs involved. Even if this is true, it is evident that the elevated costs of raw materials used in scientific research, the lower salaries for researchers, and the scarcer funds available for scientific projects in Latin America have been met with increased foresight and creativity, intense volunteering work by students, as well as careful planning and active search for international collaborations and cooperative interactions. In addition, the excessive demands – by granting agencies – for increased quantity of publications (number of S&E publications increased dramatically in the last decade in Latin America: 2.9-fold increase, from 1988 to 2001 (Hermes-Lima and Navas, 2006)), preferentially in 'high impact journals' (De Meis et al., 2003a), have caused relevant stress and burnout among researchers, especially among the younger ones (De Meis et al., 2003a, 2003b). This has had a negative effect on creativity and in the production of quality-research among Brazilian scientists (De Meis et al., 2003b; Hermes-Lima, 2005).

As evidenced by the manuscripts published in this second special volume of *Comparative Biochemistry and Physiology* the scientific research in Latin America includes a wide variety of topics (see Table 5) including classic physiology (studies on thermoregulation and digging in a rodent (Luna and Antinuchi, 2007), role of chemoreceptors in eliciting the chemocardiac reflex and evoking body movements of a crab (Aggio and Freitas, 2007), and fish cardiophysiology (Rocha et al., 2007)). Other topics covered are oxidative stress (and its relation with dehydration (França et al., 2007), arthropod development (Freitas et al., 2007) and food restriction (Luna-Moreno et al., 2007)) and metabolism and endocrinology (including fatty acid metabolism (Bellini et al., 2007), expression and regulation of progesterone receptors (Camacho-Arroyo et al., 2007) and glucose metabolism in a tick (Moraes et al., 2007)). Topics in neurobiology and proteomics include studies on neurotransmitter transporters (Cheluja et al., 2007) and snail protease inhibitors (González et al., 2007), a snake venom coagulant (Magalhães et al., 2007), the kinetic properties of a shrimp Na, K-ATPase (Mendonça et al., 2007) and a membrane-bound alkaline phosphatase (Simão et al., 2007).

While some of the listed manuscripts propose the use of unique biological systems to study nutrition, energetics and reproductive biology (Bosco et al., 2006; De Andrade et al., 2006; Luna and Antinuchi, 2006; Vinagre et al., 2007) or suggest novel approaches to control parasites and insects (Macedo et al., 2006; Maya et al., 2007), other studies address environmentally-related topics (Almeida et al., 2006; Rodríguez et al., 2006; Vega-López et al., 2007) or describe seasonal variations in biochemical and physiological parameters (Vinagre et al., 2006; Malanga et al., 2007). The study of Andrade et al. (2007) addresses the pathophysiology of the pulmonary edema induced by scorpion venom, while the study of Frey et al. (2007) suggests that alkyl

Table 5

A. Geographical areas involved in the CBP-Latin America project.	
Argentina	12.4%
Brazil (São Paulo)	24.1%
Brazil (other states)	29.2%
Chile	6.6%
Colombia	0.7%
Cuba	1.5%
Mexico	21.9%
Uruguay	2.2%
Venezuela	1.5%
Total	**137 manuscripts**
B. Research fields covered in the CBP-Latin America project	
Classical physiology	24.1%
Biochemistry of oxidative stress	20.4%
Protein science	16.1%
Metabolism and endocrinology	14.6%
Ion transport biochemistry	4.4%
Biochemistry of reproduction and development	3.6%
Neurobiochemistry	2.9%
Toxicology	2.9%
Lectin biochemistry	2.2%
Other topics on biochemistry	8.8%

Distribution of manuscripts handled for the CBP-Latin America project between May 2005 and July 2006 by A. region and B. research area.

gallates are selectively cytotoxic against tumor cells. Finally, a study from Mexico provides an intriguing link on the physiological stress of breeding with the deterioration associated with aging at the cellular level (Königsberg et al., 2007).

Twenty-four other studies highlighting the state of the art of comparative science in Latin America were published in our first special issue (*Comparative Biochemistry and Physiology C*, vol. 142, issue March–April, 2006; see: Hermes-Lima and Navas, 2006). Therefore, Latin America, in addition to being rich in natural resources and biota, has a body of highly capable scientists who have provided evidence that, with a relatively small increase in R&D investment, they are capable of taking scientific research in the less developed Americas to the same competitive level as more developed countries.

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