(Neuro)Science for education: Start of a new era

Science has become a great achievement of civilization, not only for helping us understand the universe, the earth, and ourselves, but also for creating proposals and solutions that might be useful in social practices.

Author/s:

Roberto Lent
Professor, Institute of Biomedical Sciences, Federal University of Rio de Janeiro, Brazil

Theme/s:

Future of education and learning

This report arises from Science of Learning Fellowships funded by the International Brain Research Organization (IBRO) in partnership with the International Bureau of Education (IBE) of the United Nations Educational, Scientific and Cultural Organization (UNESCO). The IBRO/IBE-UNESCO Science of Learning Fellowship aims to support and translate key neuroscience research on learning and the brain to educators, policy makers, and governments.

Executive summary

Science has become a great achievement of civilization, not only for helping us understand the universe, the earth, and ourselves, but also for creating proposals and solutions that might be useful in social practices. The scientific enterprise is structured in many countries as a blend of basic and applied research with technological developments, what became known as translational research. While engineering and health have profited greatly from this social construction for many decades, so far, education has not. However, with the great progress of neuroscience as a means to understand the brain and its workings, together with the confluence of many other disciplines, from economics to molecular biology, from social psychology to computer science, a new era is at the horizon. It is now time to provide education with scientific evidence in order to transform the educational systems of all nations into a more efficient, socially rewarding system.

Why and how science is useful for social practices

One of the most important advances, worldwide, at the transition between the 20[th] and the 21[st] centuries was the consolidation of the concept created by the American political scientist Donald Stokes[1] (1927-1997) of **research inspired by use**, employed with great success in health and in engineering in almost all countries of mid/high level of socioeconomic development.

This concept built on the idea of **translational research**, originated from a famous report by the American engineer Vannevar Bush[2] requested by US President Franklin Roosevelt after the Second World War. Bush's report aimed at planning a great effort to develop basic and applied sciences in order to solve mainly the health problems that afflicted mankind at that time. According to this concept, there would be a logical and operational sequence from basic science to technological research, innovation, and social appropriation of discoveries. Basic science, therefore, still remained separate from applied science and technology. To overcome this segregation between them, and stimulate not only scientists but also policy makers and funders to join their efforts and work motivated by potential applications of social interest, Stokes proposed a sort of scientific ecosystem. In this system, all research approaches would converge and collaborate both to answer the fundamental questions about nature and society, but also to generate alternatives to practical issues demanding a solution.

Stokes' conception about the various alternatives was that of quadrants (see Figure 1): **pure, basic research**, as illustrated by the atomic physicist Niels Bohr (1885-1962); **pure, applied research**, of which Thomas Edison (1847-1931) was an icon for the invention of the light bulb; **applied, basic research**, a quadrant left empty by Stokes but filled by myself to underline contributions internal to science, as that of Carl Linnaeus (1707-1778), who developed the well-known classification of species used by scientists to organize their findings. The most important quadrant, **research inspired by use**, was that of Louis Pasteur (1822-1895), whose work was inspired by French wine producers who wanted to protect their products from souring. Pasteur revolutionized basic science by defeating the prevalent idea of a spontaneous generation of life, and also created a technique, still used today, to sterilize liquids (known as *pasteurization*). Pasteur's quadrant, therefore, accommodates all scientific initiatives that respond to both interrogations at the same time: fundamental questions and practical issues.

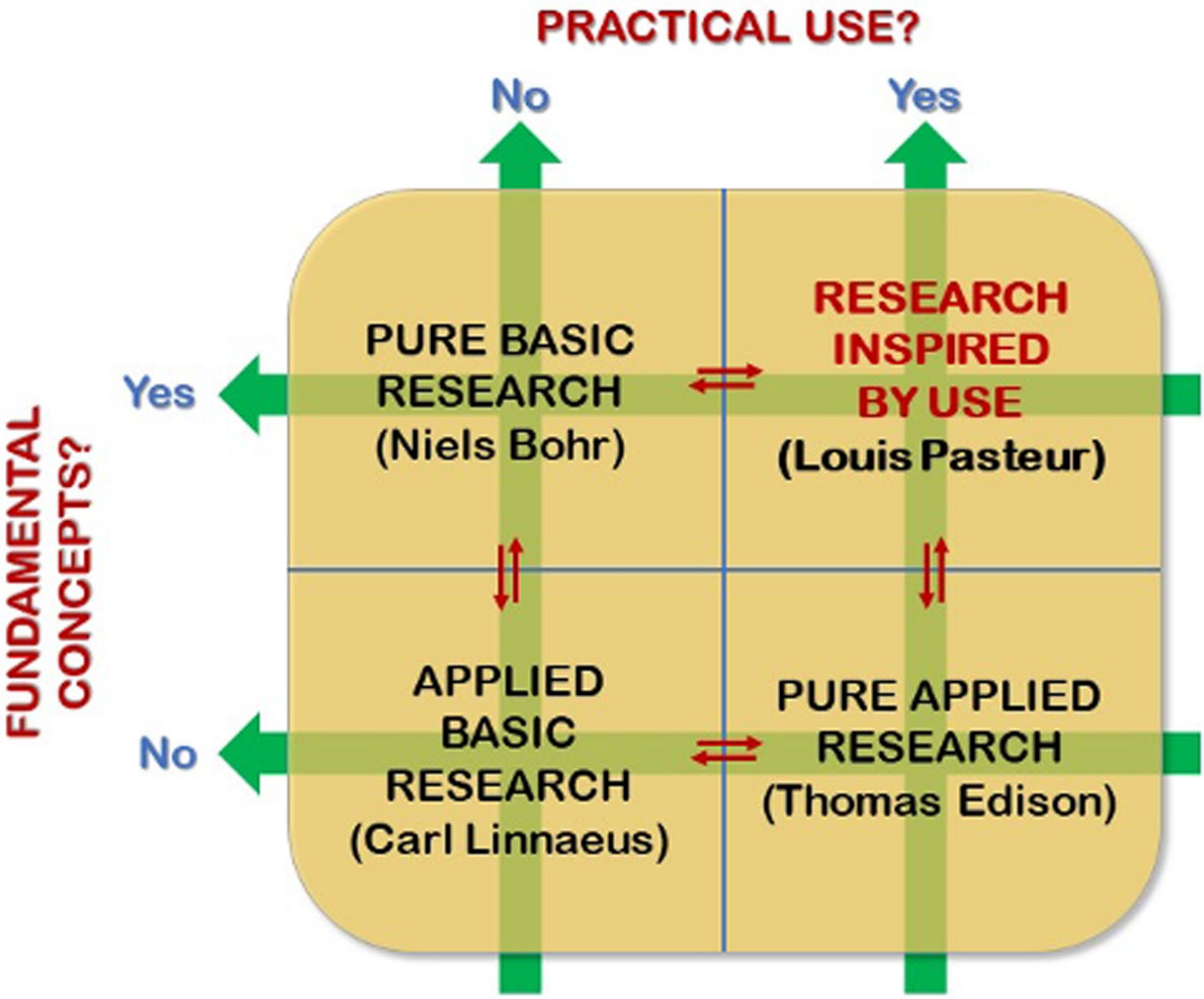

Figure 1. Diagram based on Stokes' quadrants that describes the different alternatives for research, and famous representatives of each of them.

Translational research, either conceived linearly after Bush, or bidimensionally, as in Stokes, has flourished worldwide particularly in health. Many institutions were created in different countries to deal with health problems such as cancer, developmental disorders, infectious diseases, consequences of trauma, and many others. The result of these six decades and more of investment has been a great improvement in health conditions worldwide, exemplified strongly by the steep decrease in child mortality and pronounced increase in life expectancy even in countries still plagued by inequality and poverty[3].

The astounding contradiction of this historical pathway is that the same has not happened in education!

Building an ecosystem of science for education

An ecosystem is usually defined in dictionaries as a community of organisms interacting with their environments. I use this definition here to mean that the proposals of Bush and Stokes should be adopted to generate national and international systematic efforts to foster research inspired by education, or, as it is named in Brazil, science for education.

There is still no clear perception by governments, policy makers, and citizens, even in developed countries, that such an ecosystem of translational research focused on education is not only possible, but necessary. Science is already able to understand much about how the human brain learns, which possible mechanisms can speed up learning and memory, which technological innovations could be validated by studies similar to clinical trials to scale up education in the classroom. Also, we know a lot about which cognitive and social-emotional competencies future citizens should display to become more and more participatory and cooperative, as well as to fulfill roles in employment that are more and more automatized and informatized. The governmental and private structures created everywhere to foster health with evidence-based policies still have not appeared for education, and the incipient attempts to connect the universities and research institutes with the classroom have not achieved results able to multiply initiatives by policy makers, entrepreneurs, and businessmen.

Perhaps because of this historical delay, almost all educational metrics, despite great differences between countries, have remained unchanged for many years, as longitudinal assessments show[4] (see Figure 2). In the case of health, public policies not only invested in practical measures (e.g., sanitation, hospital coverage, nutritional improvements), but also in science and innovation capable of creating new options that were original and competitive in the international scenario (new therapies for degenerative diseases, new vaccines for tropical diseases, and many others). Contrastingly, in the case of education, investment has been chiefly focused on material improvements (more schools, better salaries for teachers, and others). These are obviously necessary, but have been insufficient to accelerate the growth of educational indexes and allow a real improvement aligned with the technological advances that are changing the world so fast.

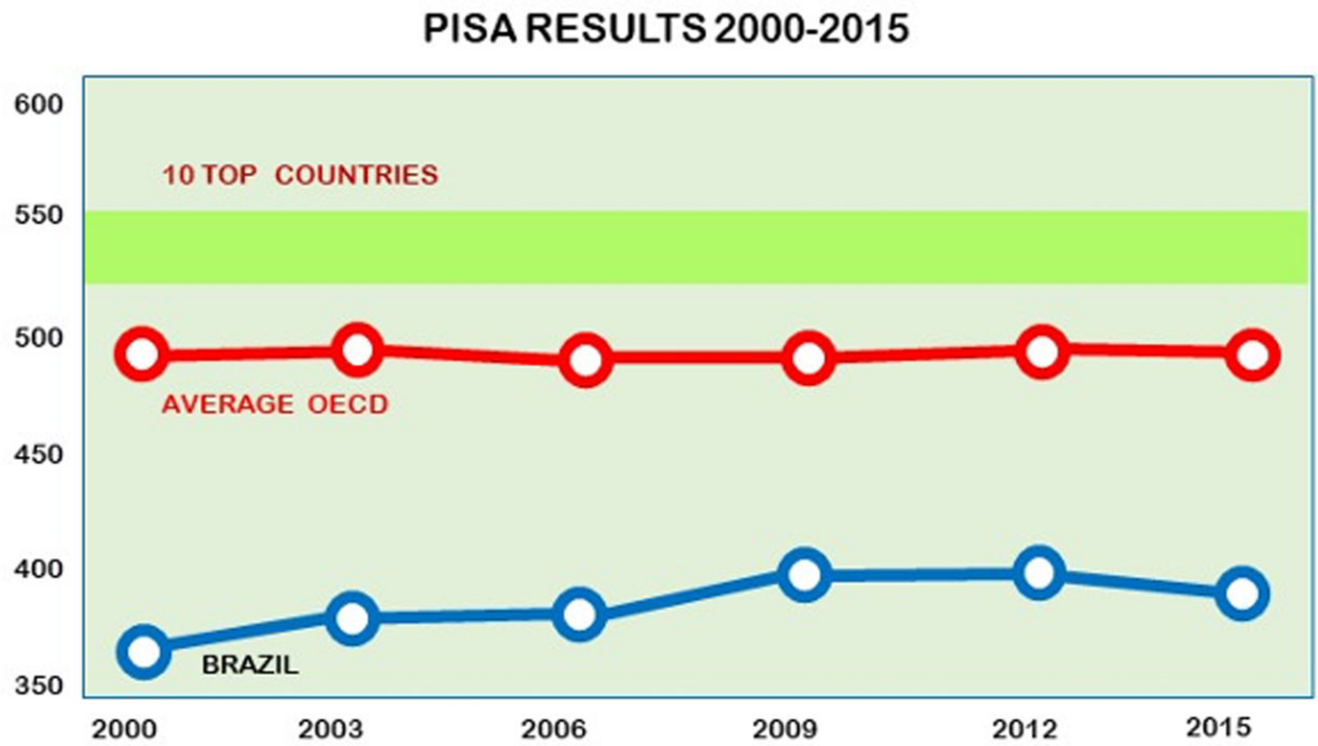

Figure 2. General results of the PISA assessments from the last 15 years, taking Brazil as an example of an underdeveloped country, in comparison with the average and with the 10 top countries. Notice that average results are quite the same through the years. An updated version for PISA 2018 will appear in December 2019.

For these reasons, the potential for the different scientific disciplines to contribute to education has become clearer and more urgent. Neuroscience, especially, is able to unravel brain connectivity and the dynamics of its functional interaction with the environment, as well as the mechanisms of brain development and plasticity[5]. These discoveries reverberate and interact with cognitive and social psychology, revealing how people think and how they relate to the family environment, school, and society in general. Also, developmental biology allows us to understand the logics of embryo formation, child development, and their disorders, as well as both their genetic and environmental determination. Along the same line, computer science and information technology—often inspired by the study of neural networks—are expanding as never before, making human beings of any age completely connected mutually, regardless of what region of the world they live in.

A new conceptual framework—advocating the confluence of all sciences to education—can create knowledge, methods, and tools that accelerate learning and mitigate disorders and consequences of low socioeconomic levels on educational outcomes. A specific contribution of neuroscience and related disciplines will be outlined below, as an example.

Emergence of neuroscience as an explanatory underpinning of education

Every time someone interacts with the environment, some aspect of this interaction persists and is stored in the brain, at least for a brief moment. The nature of this interaction and its impact on the life of the person will determine its importance and significance. The personal significance of this event for the person, on the other hand, will regulate the time of maintenance of the memory trace in the brain, and its eventual use in his/her benefit. Memory, therefore, is the ability to acquire, store, and retrieve information, while only the stage of acquisition is identified as learning. Memory is the result of learning, ascertained by the ability to retrieve it.

Thus, from the point of view of neuroscience, the word *learning* involves someone with his/her brain capturing information from the environment, storing it for some time, and eventually using it to orient subsequent behavior. The concept of learning overlaps greatly with that of memory, although both should be differentiated, considering memory as the global phenomenon, and learning as the stage of acquisition.

The environment almost always includes other individuals with their brains, in such a way that an interaction takes place between them, mediated by their brains. In this context, learning becomes a reciprocal exchange, because interactive brains learn at the same time. This is particularly important for human beings, since we live in society, what means a set of complex and frequent interactions between subjects, at a large scale.

Learning can assume an infinity of forms in daily life, some as simple as observing a still object, others very complex such as playing a musical instrument in synchrony with an orchestra. Newborn babies learn simple things, but they soon also discover the best strategies to learn more complex (and interesting) things that are around them. They learn how to learn. By acquiring this set of cognitive and cultural tools, youngsters and adults multiply extraordinarily this ability, becoming capable of storing and at anytime retrieving a gigantic amount of information. Besides biology, human society, as a result of the complexity of the task of capturing the astounding quantity of information available in the environment, has developed a structured and planned way of facilitating this ability, and created what became known as education.

Education, therefore, is a socially structured way of learning, and of learning to learn. It is also reciprocal, because it involves at least two parts—apprentices and teachers. However, education is reciprocal but not symmetrical. It ought to be dialogical, as defined by the Brazilian Paulo Freire[6] (1921-1997), offering the two parts moments of great interaction and exchange. Obviously, in current times teachers can develop tools that will substitute for their role at times—books, kits, games, videos, and many others.

The reciprocal interaction between apprentice and teacher is basically an interaction between two brains. Both have to establish mental contact, using some form of communication (verbal, written, or other), as well as sensory contact (visual, auditory, tactile), and synchronized motor behaviors, to communicate properly. With time, the two interacting brains end up by changing themselves mutually, because they transmit and store information one to/from the other. To perform such a gigantic task, the brains make use of a very important property— neuroplasticity[7].

Neuroplasticity can be defined by the property of every neural system to change itself dynamically as a result of interaction with the environment[8]. Even very simple organisms such as invertebrates, whose nervous system has a small number of neurons that may not reach one thousand, show evidence of neuroplasticity. This is the case of the worm *Caenorhabditis elegans*, with about 300 neurons, and of the sea slug *Aplysia californica*, with about 18 thousand neurons. In more complex nervous systems, such as the human brain, neuroplasticity assumes many forms, and manifests itself in all the 86 billion neurons and thousand trillion synapses of our brains[9].

An example of translation, from bench to the classroom

There are many examples of basic scientific knowledge that transform into practical alternatives in education. For the sake of conciseness, I will concentrate on one that tackles an issue of utmost importance: the human skill to read and write, developed by culture to represent the biologically acquired ability to speak.

In adults, a set of regions in the left hemisphere of the brain is consistently activated when an individual is asked to read something. This can be shown by recording brain activity using functional magnetic resonance imaging and other techniques. In preschoolers, it has been shown that learning to read gradually mobilizes these regions in the left hemisphere and increases their connectivity as they acquire this competence[10]. Besides, the neural network for reading is consistent in various cultures, with similar topography in the brains of Japanese, Chinese, or Roman alphabet readers. Noticeably, reading is a complex function[11] involving not only a perceptual component specialized for the identification of graphemes (letters, words) and its correlation with phonemes (sounds of language), but also many other different components in charge of coordinated eye movements, attentional focusing, understanding, imagination, working memory, etc.

Despite some controversy related to the participation of some specific cortical regions on reading, a so-called reading network can be defined in readers. It is a good example of neuroplasticity, since written language is a recent acquisition of human culture—not more than four or five thousand years—very short times for participation of natural selection in the evolution of specialized networks[12]. By knowing the network of regions active in reading tasks of different nature, one can also know which are defective in dyslexics (i.e., children who have difficulties in learning how to read despite lack of any other intellectual impairments).

This basic knowledge has inspired an Israeli group of researchers to develop an instrument (RAP, *Reading Acceleration Program*) designed to accelerate the slow reading of developmental dyslexics, and perhaps help them keep up with typical kids[13]. They performed a very simple experiment (see Figure 3A) in which individuals looked at a computer screen where a sentence was projected. While they were reading the sentence, the letters were erased along the direction of reading (left-to-right, in English), first very slowly, then gradually faster in order to force the readers to focus and increase their attention. When the sentence disappeared, a multiple-choice test of comprehension was given to be sure that reading was followed by appropriate understanding.

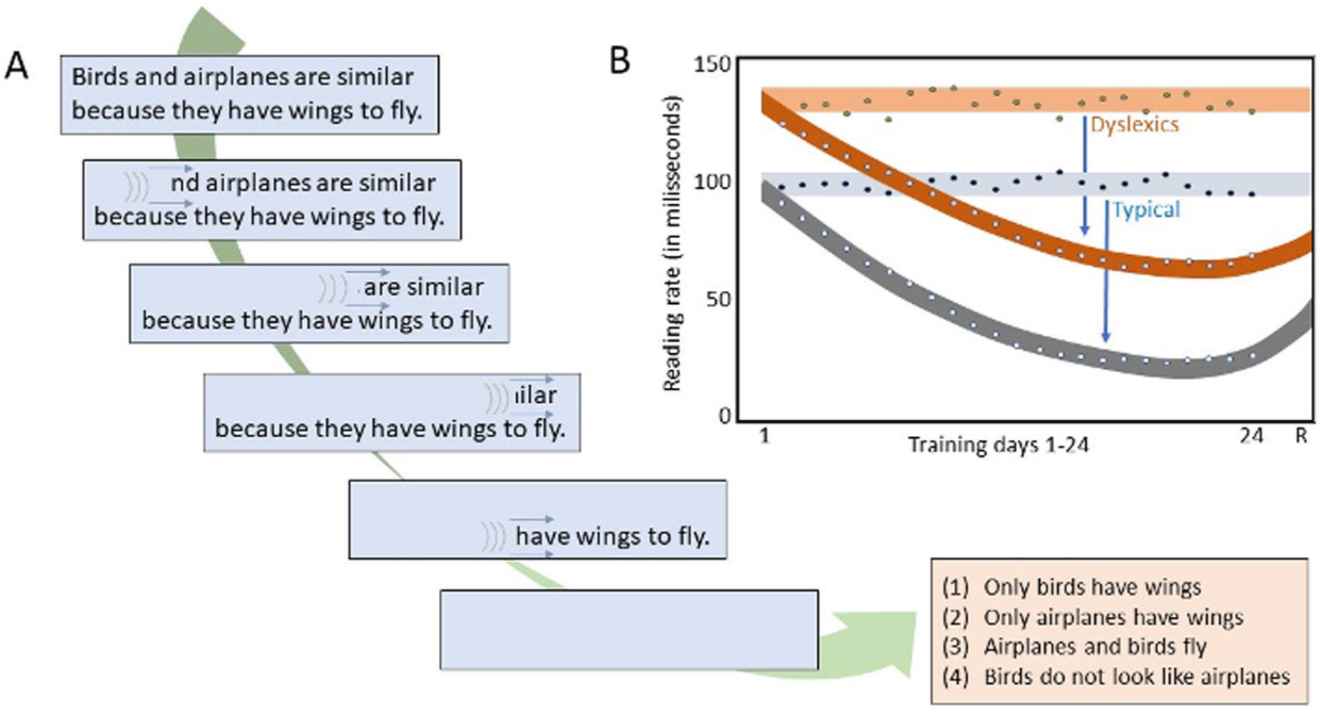

Figure 3. The RAP experiment consisted of training the participants to undertake progressively accelerated reading of sentences as in A, maintaining comprehension. B shows the results for dyslexics and typical individuals. Notice that while dyslexics improved (less time to read after training), typical individuals also did. Curves in B were modified from Breznitz et al. (2013)[12].

After training the participants for many days, the researchers had access to their longitudinal performance, represented by decrease of reading time with full understanding. Not only that, they recorded the activity of brain areas associated to the reading network using different techniques, from functional magnetic resonance imaging to electroencephalography. Results showed that the performance of dyslexics after training improved so much as to become equal to typical readers without diagnosis (controls) who had not received any training (see Figure 3B). Also, brain imaging showed increased activity in attentional regions of the prefrontal cortex, more than that of the inferior temporal cortex related directly to the reading processes. The great surprise was that a third group of typical participants of the study, after being trained as much as the dyslexics, improved substantially their speed of reading, and became capable of performing with much greater speeds than the untrained typical controls.

This example serves only to illustrate the point that a confluence of basic science with applied research, involving different disciplines with special emphasis to neuroscience, is able to translate findings "from bench to the classroom," an expression that emulates the classical saying relative to health: "from bench to bedside."

Science-based education and the future of societies

Education has been recognized as a key factor to improve economic and social development in different countries, reduce inequalities, and promote the well-being of large amounts of people worldwide. Of course, there are many measures of well-known efficacy that need to be taken by policy makers and governments to improve and democratize education. Nobody disputes the relevance of attributing high social value to teachers and rewarding their work with good salaries. Also, there is no doubt that teachers' training is a key factor for the success of education. Other measures are also well-known as positively impacting education: whole-day schools maintained in good material conditions, healthy nutritional options for students while in school, good standards of school management, and many others.

What is usually neglected, or still not foreseen in most countries, is the importance of investing strongly on translational science for education. There have been some initiatives in a few countries to establish laboratories, institutes, or centers designed to foster this alternative. But in fact, no country so far has envisaged the crucial importance of creating the ecosystem defined above, to channel research initiatives to the problems of education. Why would this new policy be so important?

Science provides education with robust evidence that could support new proposals for educational policies, most of which are still intuitive or ideological. Of course, evidence-based educational interventions have lower risk of failure, what would optimize resources and save time. There are two ways by which scientific evidence can be collected. One is performing periodic assessments after some time a new intervention is tried. I call it **reactive research** (assessment). In this case, although assessment can be scientifically rigorous, the initial interventions are not, necessarily. Although of great importance, it delivers analytical results only after the interventions are close to end. If they are found not to have been successful, the time spent should be considered lost. The other alternative is **proactive research**. In this case, the interventions are based on scientific evidence from the start. The risk, then, is lower. The example on reading acceleration, given above, represents this alternative.

The insertion of science-based proposals into educational policies, therefore, is the only way to cope with the fast pace of change in labor profiles, technological innovation, communication patterns between people, and in the social and economic organization of societies. To cope with the great speed of change, countries must be prepared, and the way to achieve this is to invest strongly in providing education with scientific evidence. International competition is somehow cruel. Those countries that do not participate in this race from the start will have terrible difficulty in the future to keep up.

References

1. Stokes, D.E. *Pasteur's Quadrant*, Brookings Institution Press, Washington DC, USA (1997).

2. Bush, V. *Science, the Endless Frontier, a Report to the President*: https://www.biodiversitylibrary.org/item/26633#page/5/mode/1up (1945).

3. World Health Organization, *Global Health Observatory*: http://www.who.int/gho/en (2019).

4. Organization for Economic Cooperation and Development (OECD), *Programme for International Student Assessment (PISA)*, http://www.oecd.org/pisa/ísa-2015-results-in-focus.pdf (2019).

5. Meltzoff, A.N.; Kuhl, P.K.; Movellan, J.; Sejnowski, T.J., Foundations for a new science of learning, *Science* 325:284-288 (2009).

6. Freire, P., *Pedagogy of the Oppressed*, New York, Continuum (1970).

7. Chang, Y., Reorganization and plastic changes of the human brain associated with skill learning and expertise. *Front. Human Neurosci*. 8:35 (2014).

8. Tovar-Moll, F., Lent, R., The various forms of neuroplasticity: biological bases of learning and teaching. *Prospects* 46:199-213 (2016).

9. Azevedo, F.A. *et al*. Equal numbers of neuronal and nonneuronal cells make the human brain an isometrically scaled-up primate brain. *J. Comp. Neurol.* 513:532-541 (2009).

10. Moulton, E. *et al.* Connectivity between the visual form area and the parietal lobe improves after the first year of reading instruction: a longitudinal MRI study in children. *Brain Struct. Funct.* 224:1519-1536 (2019).

11. Vogel, A.C. *et al.* Functional network architecture of reading-related regions across development. *Brain Lang* 125:231-243 (2013).

12. Dehaene, S.; Cohen, L., Cultural recycling of cortical maps. *Neuron* 56:384-398 (2007).

13. Breznitz, Z. *et al.* Enhanced reading by training with imposed time constraint in typical and dyslexic adults. *Nature Comm.* 4:1486 (2013)

[1] Parts of this text were based on my book *O Cérebro Aprendiz* (The Apprentice Brain, 138 pp.), published in 2019 by Editora Atheneu, Rio de Janeiro, Brazil.