SCIENTIFIC RESEARCHERS: THE SUCCESS STORY OF A UNIVERSAL COMMUNITY

INVESTIGADORES CIENTÍFICOS: LA EXITOSA HISTORIA DE UNA COMUNIDAD UNIVERSAL

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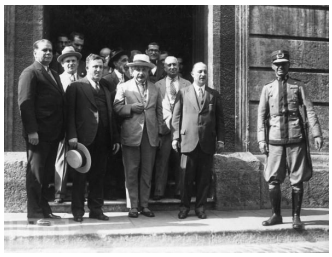
Albert Einstein is world-famous as a symbol of physics, and of science in general. In particular, the General Theory of Relativity might be the last truly epoch-making breakthrough, which was achieved by an individual scientist (although Einstein needed assistance by mathematicians [1]); meanwhile science is more and more an issue of collaborations.



En la Sociedad Cubana de Ingenieros.

Figure 1. Albert Einstein during his visit to Havana. The picture bellow shows him writing in the *Golden Book*.

During his life Einstein was also a media star, and he is still frequently quoted in all kind of contexts, often beyond science, even though these citations have to be taken with caution (his lifetime of 76 years was hardly sufficient to make all the statements quoted by him).[1]

Here we refer to one citation by Einstein, which is not among the most famous ones, but which is well documented. In 1930, while in transit in Havana, he wrote in the guest book of the Geographic Society, the *Golden Book*, the following two sentences:

"The first truly universal society was the society of researchers. May the coming generations establish a political and economic society which insure us against catastrophes."

This message is cited in a historical account by José Altshuler [3], who questions "What exactly did he mean by this?". Although the interpretation certainly requires some speculation, it does not appear all that mysterious to me. Here I am going to comment on these two statements one by one.

I. THE SCIENTIFIC COMMUNITY

Let us first sketch the society, or community, of researchers that Einstein referred to — what does it look like today? UNESCO defines researchers as "professionals engaged in the conception or creation of new knowledge. They conduct research and improve or develop concepts, theories, models, techniques, instrumentation, software or operational methods". According to this definition, there are today about *8 millions of researchers* [4], which represent 0.1 % of the world population. This is far more than in past periods, not only as an absolute number, but also as a fraction of humanity.

We assume that Einstein had *natural science* in mind, which is more specific, but which still includes astronomy, biology, chemistry, geoscience and physics. Hence we are going to refer to natural science, which describes Nature in a systematic manner, based on observation and logical reasoning.

Of course, the scientific community is divided into numerous sub-communities and sub-sub-communities. If we particularly focus on *physics*, the community shrinks below 1

[1] For instance the authenticity of the famous citation, according to which Einstein denoted the introduction of a Cosmological Constant as his "biggest blunder" (or "größte Eselei" in German), is controversial [2]. In any case, this constant is now appreciated as the most obvious explanation for the accelerated expansion of the Universe.

[2] The estimate of 1 million physicists in Ref. [5] refers to the members of national physics societies around the world. It includes, however, some members, who are not researchers, in particular physics teachers.

million [5],[2] and even within physics nobody has an overview over all branches anymore. This is a facet of *specialization*, a generic trend of human history. Enrico Fermi was one of the last researchers who was very successful both in theory *and* experiment, and Lev Landau was perhaps the last physicist to contribute outstandingly to practically all branches of theoretical physics.

Figure 2. Top left: Enrico Fermi (1901-54), top right: Lev Landau (1908-1962) and bottom: Satyendra Bose (1894-1974), three pioneers in statistical mechanics.

As an example of a specialized sub-sub-community, the author works in Quantum Field Theory in the Lattice Regularization, a field which involves $O(1000)$ researchers. A significant part knows each other in person, in particular from the annual Lattice Conferences, and people involved over a long period know each other at least by name. This is not a *collaboration* in the usual sense; only small groups of up to $O(10)$ persons work directly together, and publish papers jointly. Still, the entire community does collaborate in the sense of aiming at the same goal, to elaborate results in Quantum Field Theory beyond the perturbative expansion, *i.e.* results that are computed — by means of Monte Carlo simulations — directly at finite field couplings, which is the realistic setting. The most prominent aim is to solve Quantum Chromodynamics at low energy, which is expected to be the fundamental theory underlying nuclear physics.

In this sense, the entire "lattice community" does represent *some kind of collaboration*, working on a common goal, although the work is performed in small groups, even with occasional rivalities. Nevertheless the general atmosphere at the annual conferences, where several hundred members of this community meet, is friendly. There is some mentality in common, along with a specific *jargon*, similar working experience and ways of thinking.[3]

These characteristics can basically be extended to the entire physics community, and even to all scientific researchers. The unifying elements become less detailed when we consider a broader community, where most associates do not know each other, but the fundamental point persists: it is a worldwide community, embracing all continents, which shares a common conceptual approach and methodology of their work, along with a common goal. Scientists assume Nature to behave in a systematic manner, following a logical scheme, which they explore. This is opposed to sudden irregular jumps ("miracles"), or obviously absurd correlations, as they are claimed *e.g.* in astrology. The core of the methodology are systematic observations on the one hand, and the derivation of Laws of Nature and their implications on the other hand. Physics describes the world most directly in *mathematical terms,* an approach, which is tremendously successful (the question *why* this works so well [6], however, is rather philosophical).

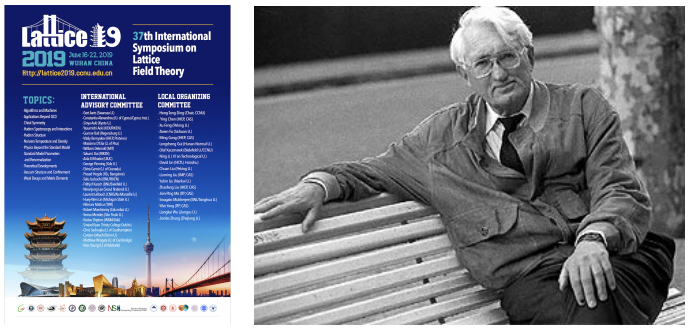


Figure 3. On the left: poster of 37th International Symposium on Lattice Field Theory, 2019, in Wuhan. On the right: Jürgen Habermas, contemporary philosopher interested in the social impact of science and technology.

An essential "common denominator" of natural science are (relatively) clear criteria for deciding whether or not some work is valid (unlike *e.g.* art, literature or philosophy): it must agree with observations, and be consistent. For a postulate to be significant in science, it must be non-trivial and withstand stringent falsification, as Karl Popper emphasized [7]. Then it will be recognized and — if it is very important — it enters the textbooks. A non-falsifiable statement is not scientific, and a claim, which is disproved, or does not prove useful, will be dismissed; this was the fate of the aether, for example, and currently supersymmetry is in danger of this destiny.

Based on these clear-cut criteria, science overcomes by its own dynamics any frontiers of nations or ethnic groups. It therefore forms a *global community,* concerned with the Laws of Nature, which hold worldwide, at any time (unlike juridical laws). This leads to joint efforts beyond any borders: for instance, when Einstein received a letter from the Indian physicist Satyendra Bose on quantum statistics, he translated it into German and submitted it on Bose's behalf to the renowned journal *Zeitschrift für Physik* [8]. Today technology drastically simplifies global communication, and even the editorial process of international journals is globalized.

The scientific criteria imply that it does (ideally) not matter *who* postulates something, and where he/she comes from; it just matters whether the postulate is correct and scientifically

[3] A rigorous analysis of the social behavior at scientific conferences might be a project for modern ethnologists. My impression is that a friendly atmosphere generally dominates.

relevant. Moreover, the concept of science is independent of any particular ideology, unless one considers the scientific way of thinking itself as an ideology, as discussed by Jürgen Habermas [9].

These are points in common, which characterize the scientific community, a minor fraction of humanity: we have mentioned an estimated number of 8 millions of researchers, similar to the population of Papua New Ginea, Switzerland or Sierra Leone, but less than the one of Cuba. This community is tiny compared to the four largest religions, each of which claims over 500 millions of members, but science has nevertheless a significant impact on humanity. It is not unusual that a small minority enjoys wide-spread attention: for instance the FC Barcelona consists of very few people, but it has over 100 million followers on Facebook. Worldwide we estimate some 130 000 professional soccer players (the world's most popular sport), which are given much more media attention (and higher salaries) than scientific researchers. The impact of science, however, is more profound than sport news:

- First, science is the foundation of technology, which is generally appreciated as a source of wealth and comfortableness. However, the impact of technology is not under the scientists' control, and it is not always beneficial for society but occasionally ambivalent, as we discussed elsewhere [10]. Still, even people with a mentality far from science are happy to benefit from technological achievements, for instance in health care, transport and communication (even the retired pope Benedict XVI uses a cardiac pacemaker, and the FC Barcelona could not attain such a huge number of followers without modern communication technology).

- Second, science has a strong influence on the public view of the world by shedding light on the mechanisms of Nature. For instance, the modern understanding of a thunderstorm replaces mythological pictures of the past. A practical benefit is that we now know how to protect ourselves from lightenings.

  In the 19th century, philosophy had a powerful impact on humanity, but nowadays the aforementioned Habermas is probably the only widely known contemporary philosopher. Since the 20th century, despite some persistent scepticism, it is natural science that shapes the established view of the world. This is amazing, in particular since science spreads its insight just by presenting facts, without tricks of mental manipulation (which are standard in commercial advertisements, making people buy useless things), nor does it employ missionaries and mass psychology (which are common practice for religious groups).

School education gives increasing importance to science. Of course, the vast majority of school children won't become scientists, and won't remember much *e.g.* of their physics classes in their later lives, but many do internalize the method of logic reasoning to approach a question and solve a problem. In this sense, science and mathematics carry on the efforts of the Age of Enlightenment.[4]

Still there is sometimes fierce resistance against scientific insight. This can be based *e.g.* on religious dogmas, or on a psychological bias against accepting scientific facts: the famous insights by Galileo and Darwin both deprived our planet and humanity of its very special rôle, which people assumed and liked before. These paradigm shifts were not easily welcomed, and even in 2017 a Gallup poll revealed that 38 % of US citizens keep believing that "God created humans in their present form at one time within the last 10 000 years" [12].[5] An even more striking example is the flat-earth community,[6] which is still present all around the globe, and horoscopes keep appearing in countless newspapers and magazines.

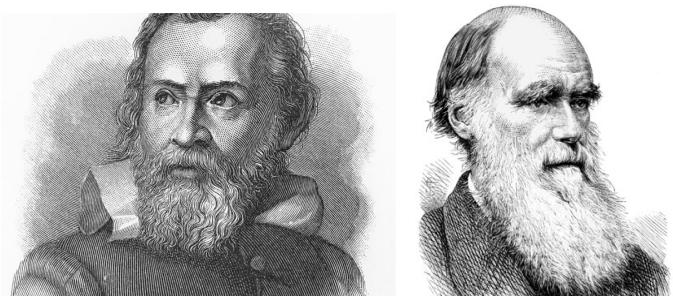


Figure 4. Galileo Galilei (1564-1642) and Charles Darwin (1809-1882): two great scientists who achieved paradigm shifts in different fields, with impacts on the public view of the world.

Despite such resistance, changes of scientific paradigms do occasionally take place [13], but in our era scientific progress is difficult to disseminate: research literature is only readable to specialists, and it is not easily communicated by popular science in a correct manner. For instance quantum physics — a major scientific revolution of the 20th century — is accurately expressed by mathematical formulae, but it is only painfully captured in terms of everyday language, which is designed for macroscopic objects, but which must be used in popular science. Hence its impact on society's vision of the world is not comparable to Galileo and Darwin, although for instance the awareness that randomness exists — in an objective sense — would be of interest to everybody.[7]

[4] This task is far from completed: for instance, a study in Mexico in 2017 [11] among third year secondary school students (age around 15) revealed that only 35.5 % are able to solve problems by performing basic operations with decimal numbers, and to express a simple relation in terms of an unknown variable. New pedagogical approaches, such as the Singapore and Shanghai method, raise hope for more effective mathematics teaching.

[5] This attitude is even present among highest authorities, as revealed in recent statements by Satyapal Singh and Damares Alves, ministers of India and Brazil, respectively (the former is responsible for Higher Education).

[6] Actually their viewpoint was already disproved by Aristotle, based on the Earth's shade observed during lunar eclipses.

[7] Einstein was much concerned with this question. He was never comfortable with this conclusion from quantum mechanics ("God does not play dice"), which has later been demonstrated by the violation of Bell's inequalities [14].

More than ever, it is a formidable challenge to produce high quality popular science; the importance of this issue is often not sufficiently recognized within the scientific community.

We conclude that Einstein's first statement appears fully transparent and correct: the researchers in natural science around the world do form a kind of community (or society) with common concepts and methodologies, which they apply to work on a common goal. The broader definition by UNESCO might include academic disciplines beyond natural science, like medicine and history, but it does still not reach out to the most powerful decision-makers on this planet, which Einstein addressed in his second sentence.

II. THE SCIENTIFIC SUCCESS STORY AS A MODEL FOR DECISION-MAKERS

Figure 5. Left: CERN from a bird-eye perspective, with white circles for the Super Proton Synchrotron and the Large Hadron Collider (small and large circle, respectively), and a dotted line for the Swiss-French border. Right: Tim Berners-Lee, the CERN employee who played a central rôle in the creation of the World Wide Web. Bottom: an illustration of ATLAS, one of the two CERN experiments that found the long sought Higgs boson in 2011/2012.

In 1986 the author had the pleasure to spend time at CERN, first as a "summer student", and again for a longer period in 1989. I experienced CERN as a multinational village, outside Geneva, with collaborators and visitors from all around world. It was impressive to see how well communication and collaboration works, and even social life is shared, simply ignoring the "cold war", or resentments between countries like Greece and Turkey; today India and Pakistan readily cooperate as Associated Member States. This spirit led CERN to tremendous success in research of high energy elementary particle physics; today it is without competition worldwide. At the "side-line" it provided numerous technical inventions, with applications ranging from medicine to the World Wide Web (WWW).[8] Since 1998, over 100 countries contributed to the Large Hadron Collider. An important tool is its Worldwide Computing Grid, which enables joint computational work in over 170 computing centers in 42 countries. This is truly a success story, which rises the question: *why does the rest of the world not follow this example?*

Extending the view beyond CERN, the collective efforts in science are generally successful: year after year progress is achieved and further questions are solved. There are exceptions — for instance, since Einstein's visit to Havana there is no substantial progress in the unification of quantum theory and gravity, despite desperate efforts. Nevertheless, the overall advancement in natural science is a success story indeed.

This takes us to the question how far all this is actually *useful*, in particular regarding Einstein's desire to *"insure us against catastrophes"*. Our protection from natural disasters, like tropical cyclones, has improved thanks to technology. However, technology is still short of really insuring us of catastrophes, as the 2004 tsunami in the Indian Ocean and the 2010 earthquake in Haiti showed; these were the worst catastrophic events in recent times, each one left about 200 000 casualties. However, I assume that Einstein was also concerned with *human-made catastrophes.*

Figure 6. Pictures of the most catastrophic events in recent times: the 2004 tsunami in the Indian Ocean, and the 2010 earthquake in Haiti.

Science can help in some of these cases: the rescue of the ozone layer in the stratosphere is a prominent example. In this case, scientific warning [15] was finally heard — in the last moment — by decision-makers in politics and economy: the production of the destructive chlorofluorocarbon gases was finally banned in 1995. Regarding global warming, this awareness has only been achieved in part so far, which is *not* sufficient. For instance in the USA, a country which is particularly harmful in air pollution,[9] the public is by no means sufficiently informed to understand the necessity of changing its habits: just 27 % of adults know that nitrogen is the dominant gas in the Earth's atmosphere [17], and the incompetence of its leadership [18] even led to the retreat from the Paris Climate Agreement.

More scientific competence in political and economic leadership, along with ethical consciousness, would be

[8] In 1993 CERN made the WWW, which had mostly been created by its employee Tim Berners-Lee, publicly accessible, free of any charge, *i.e.* it was *donated to the world*. This would hardly have happened if it were developed by a private company, and even the University of Minnesota wanted to charge a license fee for the Gopher protocol, which was considered as an alternative to the WWW at that time.

[9] In 2014, the CO_2 emission amounted to 4.97 tons per capita worldwide [16], with substantial regional differences: Subsaharan Africa 0.84, South Asia 1.46, Latin America and Caribbean 3.06, Arab World 4.86, European Union 6.47, China 7.54, USA 16.49.

highly welcome. Worldwide only few politicians have any scientific background,[10] and since the leaders appoint their advisors, the latter are unlikely to alert them when it would be strictly necessary. Apparently nobody is in a position to alert the new Brazilian government to the severe danger for life on the entire planet due to the destruction of the Amazon rainforest, the lungs of our planet.[11]

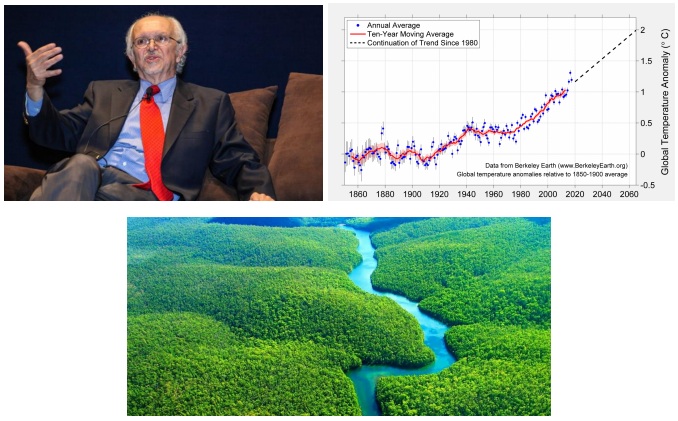


Figure 7. Left: Mario Molina, the Mexican chemist who played a key rôle in the discovery of the Antarctic ozone hole. Right: time-line of the global temperature, illustrating the rapid global warming since the 1980s. Bottom: the Amazon rainforest, where it is still intact.

Moreover there are *ongoing human-made disasters*. In particular, even in 2017 a total of 821 millions of persons suffered from hunger and malnutrition, *i.e.* one in every nine people [21]. This number keeps rising, despite massive food overproduction,[12] and millions die of preventable and treatable diseases; *e.g.* diarrhea kills more than 2000 children every day [23]. If decision-makers would be able and willing to collaborate at an international level to prevent such catastrophes, with the same harmony, efficiency and rigor as physicists at CERN, these problems would have been overcome long ago. Along these lines, a global collective effort could also do away with other evils, like illiteracy; it is hard to understand why this should be technically more difficult than discovering the gauge bosons of the weak interaction, $W^{\pm}$ and Z^0, and finally the Higgs boson.[13]

The United Nations constitute a step towards the formation of a global community which could address such urgent issues. It has proved useful at some occasions, for instance alleviating conflicts, and institutions like UNESCO, UNICEF and FAO are doing good jobs. However, the United Nations remain far below the effectiveness that would be required; in particular, it is not capable to eradicate military and economic aggression, which break international laws and cause suffering to millions and millions of humans.

In this sense, the community of scientific researchers represents a *vanguard*, an example to be followed in politics and economy. Here we finally arrive at the core of Einstein's second sentence, which he wrote in the Golden Book of the Geographic Society: he expressed it as his vision and hope for the future. Unfortunately nine decades after Einstein's visit to Havana, this is still not achieved: "globalization" takes place, but in a different sense. A collective worldwide effort to overcome ongoing disasters like malnutrition and wars should follow the examples of the scientific community's collective work to disclose the secrets of Nature. At this point, we can only iterate Einstein's vision and hope for it to finally materialize in yet future generations.

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[10] Exceptions with a background in physics are Germany's long-term federal chancellor Angela Merkel, and Mexico City's new mayor Claudia Sheinbaum. In the past, we only know of one president and four prime ministers who had a degree in physics [19].

[11] Minister Santa Rosa denotes it as "unproductive" and "desert-like", and Jair Bolsonaro lamented "It's a shame that the Brazilian cavalry wasn't as efficient as the Americans, who exterminated the Indians" [20].

[12] FAO estimates that 1/3 of the food worldwide, about $1.3 \cdot 10^9$ t per year, ends up in garbage [22], while 20 000 persons starve to death every day.

[13] A popular science account is given in Ref. [24].

[16] https://data.worldbank.org/indicator/EN.ATM.CO2E.PC

[17] Pwe Research Center, http://www.pewresearch.org/science/2016/10/04/public-knowledge-about-science-has-a-limited-tie-to-peoples-beliefs-about-climate-change-and-climate-scientists/

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