Revisiting the Pasteur Quadrant, Post-normal Science and Strategies for Research on Natural Hazards and Disasters

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Abstract:

The paper reviews two paradigmatic research strategy models: a) The Linear Research Model; a lineal one-dimensional plane model; comprising basic research at one end and applied research at the other and using the maxima that "*applied research invariably drives out from pure research"*. b) The Quadrant Model of Scientific Research; a two dimensional Cartesian plane model **[1]** characterizing four research quadrants: i) The Bohr´s Quadrant, where the quest for fundamental understanding is high, but no so regarding apply research. ii) The Pasteur´s Quadrant, where both the quest for understanding and consideration for use of the information are high ("U*se-Inspired Basic Research or Mission Oriented Research Quadrant*"). iii) The Edison´s Quadrant, where the quest for fundamental research is rather low and there is high consideration for use of the information. iv) The Empty Quadrant, where there is no considerations either for developing fundamental knowledge or for use. It is argued that research planning dealing with natural hazards and mitigation of disasters (particularly in the developing world) has to consider the use of Stokes´ quadrants and particularly focus in the Pasteur´s Quadrant. Looking into comprehensive research and the conformation of high level inter-disciplinary teams, long term financing schemes and pointing towards the implementation of Post-normal science strategies, where the dissemination of knowledge and education to society and the use of local knowledge, are critical aspects. Finally, the case of the 2010 devastating earthquake and tsunami in Chile is used as an example where the existence of just outstanding Normal-science knowledge (i.e Bohr´s Quadrant) was not enough to confront it.

Developing countries need to invest in team-organized and modern planned research regarding their own natural hazard and disaster priorities.

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Keywords

Pasteur´s quadrat, hazard, impact, research, inter-discipline, post-normal science, Chile.

Introduction

What is called "Normal Science" has been defined **[2]** as: *"research firmly based upon one o more past scientific achievements; achievements that some particular scientific community acknowledges for a time as supplying the foundations for its further practice"*. If these achievements are sufficiently unprecedented and attract an enduring group of scientist away from other unprecedented achievements, and if they are sufficiently open-ended to leave problems to be redefined, they are called by Kuhn "science paradigms". There is a beautifully description of the way in which old science paradigms are replaced by new ones, previous to the presence of a "sense of malfunction"; a prerequisite for scientific revolution; described as punctuated interludes, where scientific paradigms are been sequentially replaced **[2]**. Some of the main and initial scientific revolutions occurred around the nineteenth century that reinforced in the first half of twenty century, greatly helped to shape what we use to call the modern-world or the world where material progress has occurred at a comparative faster rate. Philosopher of the sciences and political scientists have scrutinized not only in the structure of such scientific revolutions, but also with regards to the associated scientific policies schemes implemented by leading developed countries, particularly after Word War II and at the end of the so called cold war. Donald E. Stokes **[1]** was one of such political scientists deeply thoughtful about policy processes and that deeply understood science. Stokes´ book "Pasteur´s Quadrant: Basic Science and Technological Innovations" is a land mark on the matter. On the other hand, Post–normal science (at the beginning much linked to ecological economics) is a truly new conception of the management of complex science-societal related issues **[3, 4, 5, 6]** , advocating the inclusion and integration of knowledge derived from science, but also addressing: a) uncertainty, b) value loading, c) plurality and importantly c) communication of science to society. In other words Post-normal science addresses the need to focus on complex societal-problem-solving via the coupling of science together with the relevance of human commitments and values and face epistemology as well as governance issues. This approach goes over and above concepts used in the literature such as integrative, interdisciplinary, transdisciplinary or landscape research **[7]** .

The suddenness and unpredictability of natural hazards (= naturally occurring physical phenomena caused by either rapid or slow onset of events having atmospheric, geologic and hydrologic origins on solar global, regional, national or local scales; definition according to UNESCO) such as earthquakes, tsunamis, flooding, landslides, droughts; or for the matter human-driven step by step building processes leading to earth systems towards tipping points **[8]** , such as climate change, global warming, water shortages and associated risks that seriously and dramatically affect nations. These are indeed critical research areas that urgently need to be approached via post-normal science, complemented or assisted with the so called Pasteur´s Quadrant, Research Strategy. To accomplish that, a country needs to develop well thought research plans regarding own research on natural catastrophes priorities and to allocate long-term resources. In this regards, science and technology academies, like the Kingdom of Morocco, Hassan II Academy of Science and Technology, may play a crucial role in it.

Revisiting Pasteur´s Quadrant

Around the world, governments and research institutions have approached the planning and financing of Normal science research from different angles and using various models. Perhaps two of the better known models are:

a) **The Linear Research Model** (a lineal one-dimensional plane model), comprising basic research at one end and applied research at the other **[1, 9]**. The structure of the model is that linearly basic research, leads to applied research, resulting in development and eventually into production, operations and technological innovations **[1]** . In this model, each of the successive stages depends upon the preceding one/ones and were described in "Science-The Endless Frontier: A Report to the President on a Program for Postwar Scientific Research": *"applied research invariably drives out pure research",* what is known as Bush´s perverse law

governing research **[9]** . Here, the main paradigm is that there is a tension between curiosity-driven basic research that is performed without thought of practical use or end and applied research, which tends to be planned and developed directed toward some individual, groups or users. In fact, *"basic research is the pacemaker of technological progress"* **[9]** . In USA Science was: Science --The Endless Frontier Program, and five years later lead to the creation of the National Science Foundation, a powerful research funding agency that it was thought and established independently, as much as possible, from political control **[1]** .

b) **The Quadrant Model of Scientific Research** (a two dimensional Cartesian plane model) [1] (Fig 1). In this model the vertical axis represents the degree to which a given body of research seeks to extend the frontier of fundamental understanding, while the horizontal axis represents the degree to which the research is guided by considerations of use. Stokes **[1]** characterized four main research type of quadrants: a) the Empty Quadrant at bottom left-hand quadrant, where there is no considerations either for developing fundamental knowledge or consideration for use; b) The Bohr´s Quadrant ate the upper left-hand, where the quest for fundamental understanding is high, but no so regarding considerations for use of the information; c) The Edison´s Quadrant, at the bottom right-hand, where the quest for fundamental research is rather low, by high the consideration for use of the information; d) The Pasteur´s Quadrant, at the upper right-hand, where both the quest for understanding and consideration for use of the information are high. This quadrant can be labeled as the "Use-Inspired Basic Research Quadrant" and also as the: Applied, Mission Oriented or Service Oriented Research Quadrant **[1]** .

In Stokes´ book **[1]** is found a full description about how dissents (researchers, agencies, countries) of the Bush´s one-dimensional Linear Research Model **[9]** developed different research models away from the linear one–dimensional model, for the planning, implementation and the creation of new research agencies or national research structures for the allocation of basic, applied or mixed research funds. All of them recognizing a more complex relationship between the quest for fundamental understanding and considerations for the use of the information (applied research), aiming to bridge research and industrial development according to country priorities. Nevertheless, no abandoning the idea that curiosity-driven basic research is a key part of the puzzle.

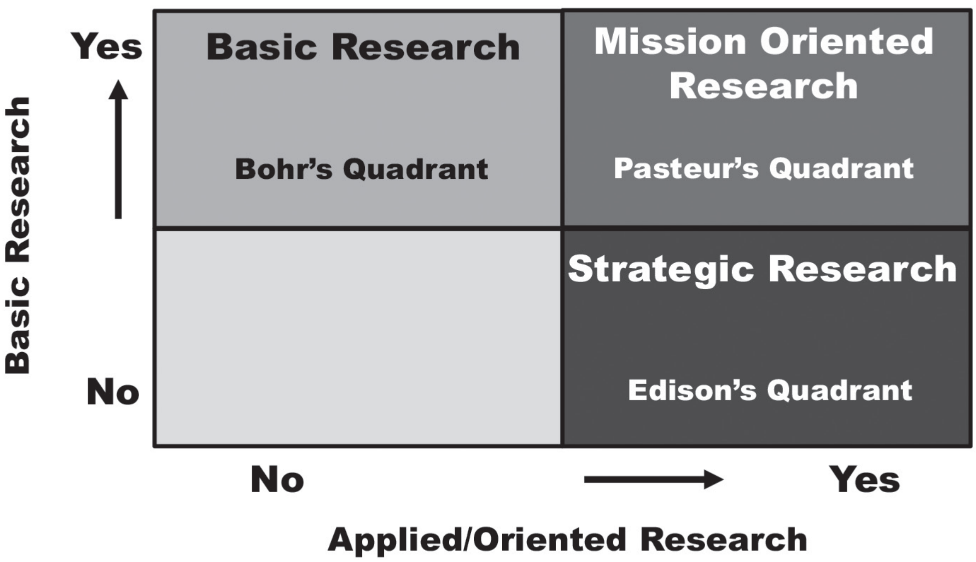


Figure 1. Stokes`Quadrant Model of Scientific Research. (Taken and modified from Stokes **[1]**).

Hereby, I pose that in many circumstances there is a need for countries to prioritize and allocate adequate long-term funds for research on natural hazards, associated risks and disasters. The strategies have to integrate interdisiciplinary teams aligned with the Mission Oriented Pasteur Quadrant. By this I mean making sure that the fundamental research to deal with natural hazards and disasters is duly developed inside the country (-obviously taken advantage of global produced knowledge-), and is the same time that advanced knowledge is indeed of high scientific quality (-judged for instance for the level, quality and impacts of publications-). But, at the same time, importantly considering the transference of the information to society and enhancing governance schemes. Here, is exactly the space to integrate a "Pasteur Mission Oriented Research Strategy" on natural hazard and disaster and associated risks in connection with the relevance of such knowledge to human communities, values and governance issues. This is to say, moving into the direction of the new paradigm labeled as Post-normal science.

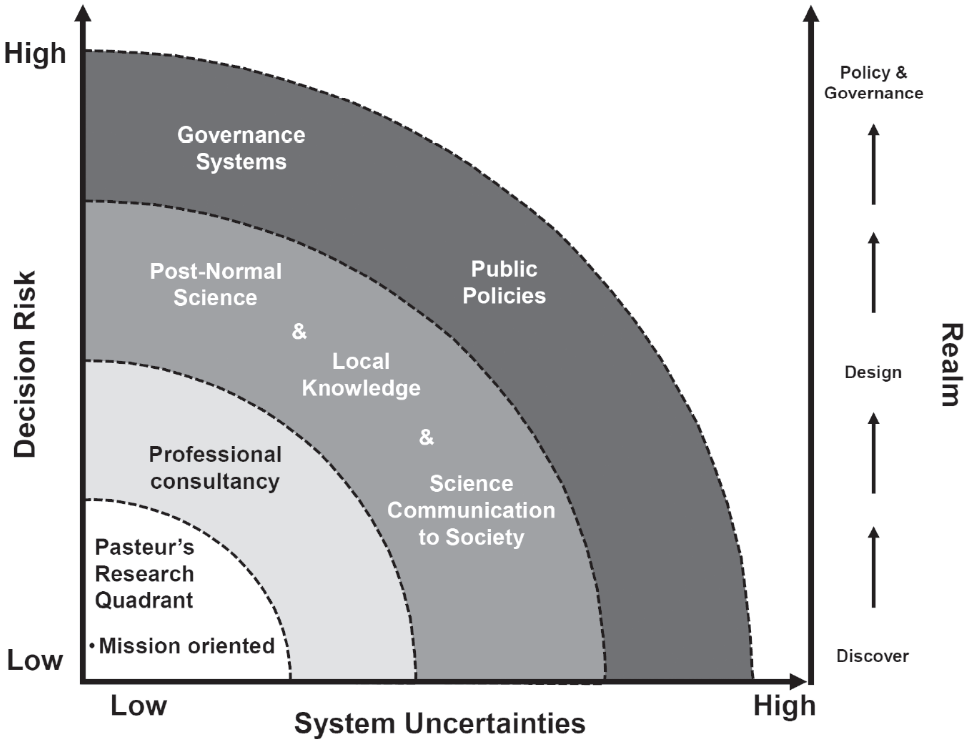
Visiting Post-modernism and Post-normal science

The so called pre-modern era was one where Normal science (see above) was practically unknown and religion and traditional knowledge were the main sources of truth and explanation of reality. In the modern era, step by step, science became the predominate source for truth to explain nature and reality. The Sun, Earth, the age of planet Earth and *hominin* fossil may serve as an example. Copernicus, a Catholic cleric, in 1543 argued that the Sun, not the Earth, was the center of the Universe, this against the well accepted opposite general believe. In 1633, Galileo was placed under house arrest by the Inquisition for endorsing this theory. At that time it was overwhelmingly accepted that the planet Earth was created around 6000 years ago. Actually, English speaking Christians accepted that God had created Earth on October 23, 4000 B.C. **[10]** . In 1778 there were proofs than indeed planet Earth was significantly older than 6000 years and that in fact its age was incalculable: it could be hundreds, millions of billions of years **[10]** . Furthermore, Darwin **[11]** , heavily influenced by Hutton´s theories**[10]** , sustained that *Homo sapiens* was descendent from an ancestor shared with the common ape. In the past 180 years we have unearthed 27 separate *hominin* fossils (-ancient and modern humans) that split of from a common chimp-like ancestor, around 7 millions years ago. Surely, 26 of them are not longer with us, but we know amazing details about their anatomies, physiologies, behaviors and about their scattering around the world. We are the last survivors of the 27 variety of *hominin* so far discovered on Earth **[12]** .

The list of scientific advances and discoveries in this and many other areas is endless. Nevertheless, narratives as those of the Scottish Enlightenment times are definitely gone. At present *"knowledge is constructed, not discovered, its is contextual, not foundational"* **[13]** . Today, we find ourselves in a post-modern world, or in the Anthropocene era **[14]** , that lacks powerful narratives and where science is not, necessarily, any longer the past gold fountain for the explanation of realities. Further, where the cultural constructions perhaps still depends on some science, but where influences are much smaller of physical sciences, much larger in the social sciences and lesser in pure than in applied science **[6]** . Hence, Post-normal science is a new conception of the management of complex science-social related issues and it focus more on aspects of problem-solving heavily impregnated by uncertainty and risks **[15, 16]** , values loading and plurality of societal legitimate perspectives **[3, 4, 5]** . Post- modernity is the time of science-societal complexities and uncertainty of human commitments and values and one marked by deep human-driven changes on earth and sustainability. Concurrently, is the time for Post-normal science, that necessarily advocates the inclusion and integration of knowledge derived from science, but now addressing, uncertainty, value loading, plurality and most important than all, the communication of science to society. The science ivory tower paradigm anchored in universities is over. It has been replaced by a complex and entangling combination of science-societal fundamental and mission oriented applied science, going through professional consultancy (if necessarily) and flowing through the turbulent waters of Post-normal science with value loading, science communication to society, and ideally reaching policy spheres and governance schemes (Fig. 2). Not a minor task.

Figure 2. Problem solving diagram .When uncertainties and risk are low, we are in the Normal-science

"discover" realm. In the middle, most often scientific expertise will be not enough and there would be a need for professional consultancies and elements of Post-Normal science; we are in the "design" realm. When risk and uncertainties are high we are in the "policy and governance" realm. Here, defensive strategies could appear, challenging even advanced knowledge. (Taken and modified from **[4]**).



Natural hazard, disaster, mission oriented research and the role of Post-normal science

According to UNESCO, natural disasters are the combination of hazards conditions of vulnerability and insufficient capacity or measures to reduce the potential negative consequences of risk. Nevertheless, natural disasters are not necessarily entirely "natural", since people can be active local or global agents of disasters (environmental human-driven hazards and disasters). Hence, flooding may be exacerbate by deforestation or the improper management of water sheds. Climate change, global warming and modifications of the carbon cycle are undoubtedly global hazards been driven by humans **[17, 18, 19]** . Not all, by many natural disasters can be greatly mitigated. As proposed by UNESCO International Strategy for Disaster Reduction, mitigations include the fields of risk awareness and assessment, building of local and global knowledge, public information, commitments and the development of appropriate institutional frameworks; as well as early warning systems including forecasting, dissemination of warnings, preparedness measures, reaction capacities and above all education. At a national level the approach to theses complex interdisciplinary fields require the adoption of forethought planning strategies at different institutional levels. There are several fields of knowledge that do require basic information (Normal-science approaches) related to different geo-bio-physical as well as socio-economic disciplines. At the nation-level research planning to deal with natural hazards and to mitigate natural disasters is one of the most fruitful field for the developing of Mission Oriented Team of Researchers (see above) and for the implementation of Post-normal science strategies, where the dissemination of knowledge and education to society, as well as the use of local knowledge, are critical aspects. It will not just be a matter of developing more up-to-day information (that

is much needed), but moreover developing/inventig new tools and mechanisms to address how to tackle complex science-social potential hazards and disaster issues impregnated by uncertainty and risks.

In this regards, the February,27th, 2010 Chilean maga-earthquake and tsunami disaster is a case worth to address. The earthquake occurred at around 4 AM and had a magnitude 8,8 MW (the fourth largest even recorded with instruments in the world **[20]**. Normal-science had predicted in 2009, that concerning the seabed fault in Chile along 35-37° S: " …, *in the worse case scenario*, *the area already has a potential for an earthquake of magnitude as large as 8-8,5, [and] should it happen in the near future"* **[21]**. Obviously, the exact date of the earthquake was not predicted. But the amount of accumulated energy in the geo-fault area, since the previous large quake in the same area in 1835 (-witnessed by Charles Darwin during his stay in Chile **[22]**, make the scientific prediction a very valid one. Indeed, this was exactly the area where the earthquake and tsunami occurred in February 2010. It can be stated that a group of scientists **[21, 23, 24]** made a proper job from a geo-physical Normal-science perspective, but unfortunately, they were no part of a integrate and comprehensive team dealing with complex earthquake and tsunami hazards in Chile, that would have the possibility to use that information in a more comprehensive and science-societal perspective. As basic scientists they just made a good job; they produced outstanding science and published in good international scientific journals. The lesson (in short) is that Normal-science is just one part (a very important one indeed!) of a Mission Oriented Research Team or a Post-normal Research Team, dealing with hazards, disasters and risks, such as earthquake or tsunamis. Nevertheless, it may be consider that regarding the occurrence of natural hazards and disasters… the population preparedness is at stake. In Chile, at the time, that mission oriented research strategy, and proper allocation of resources, did not exist. It is no possible (or proper) to speculate if the existence of such teams in Chile would had helped or nor to a better preparedness of the population, mitigating in that way the impacts and fatalities (but see **[25]**); nevertheless, the international experience signs in that direction. It seems to me that in this respect the Chilean government has learnt some lessons, since in the past two years a special Team-research Program has been developed and funded to deal with natural hazards and disasters in the country. This is a step forward in the right direction.

Conclusions

Research on natural hazards and disasters represent critical challengers for governments and particularly for the developing world. On the matter, long-term strategic research polices need to be implemented and priories to be set. Concurrently, long-term and adequate funding are absolutely essential. For instance, natural hazards (real natural ones or human-driven ones) may seriously affect economy of countries and societies as a whole for climate change **[18]**. The so called Normal-science is absolutely necessary to advance in generating curiosity-driven knowledge in these arenas, but not sufficient. Natural hazards encircle the management of complex science-societal related issues, and national research policies, strategies and tools such a those proposed by Stokes **[1]**, regarding the application of a bi-dimensional Quadrant Model of Scientific Research, rather than the usual one-dimensional Linear Research Model is worth to consider. In the tackling of national research on natural hazard, risks and disasters a mission team-research oriented strategy is suggested. Furthermore, post- modernity, and the era of the Anthropocene in which we live, calls for science-societal Post-normal science integrated approaches. Hazards and disasters are extremely complex research arenas. So Post-normal science approaches advocate that the knowledge derived from transdisciplinary scientific approaches, including, uncertainty, value loading and plurality needs to be communicated to society. Eventually the processes should lead into the direction of public policies and governance spheres. The case of the 2010 devastating earthquake and tsunami in Chile is a good example where the existence of just outstanding Normal-science knowledge, on a critical recurrent hazard for the country (earthquakes), was not enough to confront it. From this and other examples, lessons need to be derived: the costs involved in research leading to the mitigation of natural hazards and disasters are, generally speaking, small as compare to the costs of relief, recovery and lost of lives. Developing countries need to invest in well team-organized and modern planned research with regards to own natural hazard and disaster priorities.

There is most often the perception that tackling mission-oriented work will reduce the quality of research.

Nevertheless, the experience of Japan, USA and Australian indicates the contrary. For instance, in Australia the increase focus on mission-oriented research (mostly via the Commonwealth Scientific and Industrial Research Organization, CSIRO) has indeed increase Australia's ranking as one of the leading source of intellectual property **[26]**

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