CHAPTER 9

University Research comes in many Shapes

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In “The Usefulness of Useless Knowledge”, written in 1937, (Flexner, 1955) Abraham Flexner described a conversation with George Eastman: “*I ventured to ask him whom he regarded as the most useful worker in science in the world. He replied instantaneously, ‘Marconi’. I surprised him by saying: ‘Whatever pleasure we derive from the radio or however wireless and the radio may have added to human life, Marconi’s share was practically negligible.”*

I shall not forget his astonishment on this occasion. He asked me to explain. I replied to him: “*Mr. Eastman, Marconi was inevitable. The real credit for everything that has been done in the field of wireless belongs, as far as such fundamental credit can be definitely assigned to anyone, to Professor Clerk Maxwell, who in 1865 carried out certain abstruse and remote calculations in the field of magnetism and electricity. Maxwell reproduced his abstract equations in a treatise published in 1873. Other discoveries supplemented Maxwell’s theoretical work during the next 15 years. Finally, in 1887 and 1888, the scientific problem still remaining — the detection and demonstration of the electromagnetic waves which are the carriers of wireless signals — was solved by Heinrich Hertz, a worker in Helmholtz’s laboratory in Berlin. Neither Maxwell nor Hertz had any concern about the utility of their work; no such thought ever entered their minds. They had no practical objective. The inventor in the legal sense was of course Marconi, but what did Marconi invent? Merely the last technical detail, the now obsolete receiving device called a coherer, almost universally discarded.’ Hertz and Maxwell invented nothing, but it was their apparently useless theoretical work which was seized upon by a clever technician and which has created new means of communication, utility and amusement by which men, whose merits are relatively slight, have obtained fame and earned millions. Who were the fundamentally useful men? Not Marconi, but Clerk*

Maxwell and Heinrich Hertz. Hertz and Maxwell were geniuses without thought of use. Marconi was a clever inventor with no thought but use."

How knowledge created by science converts into material benefit for society became an explicit and pressing question as the 20th century ended. It is not that before then an expectation that science would create wealth, well-being and power, did not exist. It did, and the perfect testimony to that was Vannevar Bush's "Science: The Endless Frontier" report (Bush, 1945). Somehow, both the public and their representatives, accepted the idea that there is a connection between science and development, and were most of the time happy to see science advance, counting that this would bring benefits to society in the future.

The Bush report is a good starting point to discuss and understand the ways in which research can be classified. He presents a definition for both Basic and Applied research:

Basic and Applied research — **Basic research** is performed without thought of practical ends. It results in general knowledge and an understanding of nature and its laws. This general knowledge provides the means of answering a large number of important practical problems, though it may not give a complete specific answer to any one of them. The function of **applied research** is to provide such complete answers.

Presently NSF (National Science Foundation) has a slightly updated definition, that in addition defines Basic and Applied research independently of each other (NSF, n.d.):

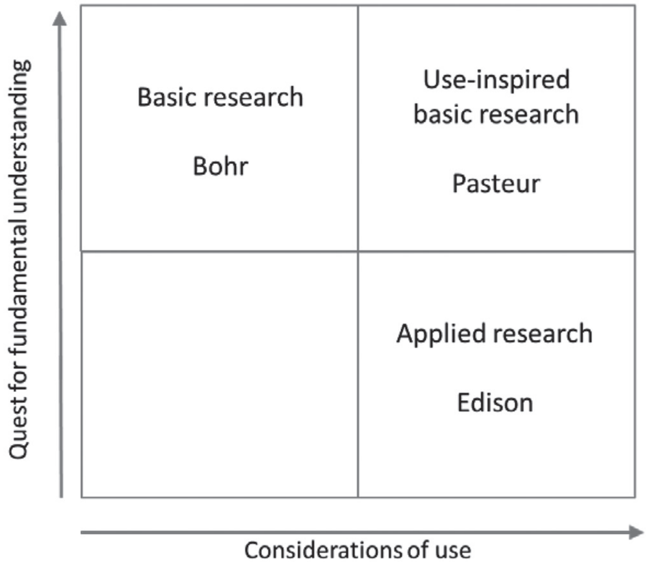
Basic research — systematic study directed toward fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind.

Applied research — systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met.

Universities, governments and funding agencies around the world have been using Bush's definition or the updated NSF definition to classify research activities, and this classification has helped the development of knowledge for many decades. However, its use presents some challenges. One immediate difficulty is the fact that the definition depends on guessing what is in scientists' minds when they decide about the topic they will study. In addition, there are situations in which obtaining *fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts* might be enough *to determine the means by which a recognized and specific need may be met*, which would make the research in question both Basic and Applied.

Fifty-two years later, Donald Stokes (Stokes, 1997) came to help, bringing a different view. He classified research in a two-dimensional diagram, considering in one axis the relevance of the research to the advancement of

Figure 2: Stokes' quadrants for classifying research (Stokes, 1997).



fundamental understanding, and in the other the considerations related to the use of the research results. To help the reader, Stokes classified the quadrants in the resulting diagram, as shown in Figure 1 (being a kind person, he did not name any scientist for the quadrant where there is no fundamental knowledge and the results are not of any use).

To my knowledge, Stokes' was the first formulation that lifted the opposition by definition that existed between Basic and Applied research. Moreover, it came in an interesting epoch, when many knowledge-related organizations in the world were feeling the pressure to produce more useful results, or results with higher and immediate impact.

THE ORGANIZATION OF NATIONAL RESEARCH SYSTEMS

Starting after World War II, many countries took action to build systems to support science, research and higher education. The basic idea was that by enhancing its science base, a nation would create ideas and train people, and these two actions would be determinant in creating development. In many places, the recipe worked for some time, until the economic difficulties at the end of the 1970s started to take a toll on government spending.

Searching for a more effective connection between science and societal needs

Most people would agree that knowledge drives development. Still, the fine mechanics of how knowledge leads to development is a subject of intense debate, more so in recent years, especially after the advent of the IT revolution brought by the invention of the transistor, integrated electronics, the personal computer and, later, the internet and the World Wide Web. Some time around the second half of the 1970s, the life sciences joined the engineering and physical sciences branch of the knowledge revolution. In both branches, the subsequent boom of start-up companies, some of which grew at a fast (or extremely fast, in some cases) pace, made clear to taxpayers and their representatives that there was an opportunity ripe to be exploited: how to create wealth from knowledge at a much faster pace than had been done before.

Governments and society in most countries started an intense debate about the “knowledge-revolution”, or the “knowledge-based-economy”, searching, in a much more explicit way than had been done before, how to optimize the connections between universities, government and the economy, for the public benefit.

The Bayh-Dole Act of 1980 was especially relevant as it raised the bar for the standards of intensity in university-industry interactions. It had an effect in many countries, as they emulated the U.S. initiatives trying to obtain more impact from university research. In Brazil, an “Innovation Law” was enacted in 2004. On the institutional level, researchers, mostly European, came up with the concept of “National Innovation Systems” (OECD, 1997). A large effort in the measurement, modelling of, and understanding of the institutional interactions ensued, as can be seen in the ever-growing series of OECD reports on Science, Technology and the Economy.

The rising cost of research, increasing the demand on governmental funding agencies and on the taxpayer, also contributed to favour the move towards applications and short-term impact. It must be remembered that members of governments, national congresses or state senates go through the budget tables with the cost of public universities and funding agencies several times each year. However, they seldom find time to pay attention to the news (when it exists) about the benefits of these organizations, which reach the decision-makers in a scattered and non-systematic way throughout the year. On top of this, universities and funding agencies are often not completely effective in transmitting to the public, and to their representatives, the information about its successes.

As a result, the national and regional policies were readjusted, changed or reinvented, to obtain more impact, which usually implied redirecting research to more applied objectives, or altogether to the creation of “innovation”.

Themes like university-industry interactions, small-business research support, measuring the impact of research results, and intellectual property protection/ licensing, became more and more common in the agenda of funding agencies, universities and research institutions. Among the consequences, there was an intensification of the debate on how research should be organized to bring maximum societal impact.

ORGANIZATION OF RESEARCH IN THE BEGINNING OF THE 21ST CENTURY

Looking for higher impact of the research, funding agencies and universities came up with new ways to classify the research objectives or the way research should be performed. Impact is a broad concept, and it might be useful to think of it along three dimensions: intellectual impact, economic impact and societal impact.

Transformative research

Intellectual impact relates to the way research results will contribute to the advancement of knowledge. The category of Transformative Research, as defined by the National Science Foundation, addresses this dimension (NSF, 2007):

Transformative *— Transformative research involves ideas, discoveries or tools that radically change our understanding of an important existing scientific or engineering concept or educational practice or leads to the creation of a new paradigm or field of science, engineering or education. Such research challenges current understanding or provides pathways to new frontiers.*

Other organizations use different names for activities similar to this category, such as Frontier Research, High-impact and High-reward. Fostering transformative research does not imply abandoning incremental research. The NSF report makes a point on this by starting with:

Science progresses in two fundamental and equally valuable ways. The vast majority of scientific understanding advances incrementally, with new projects building upon the results of previous studies or testing long-standing hypotheses and theories. This progress is evolutionary — it extends or shifts prevailing paradigms over time. The vast majority of research conducted in scientific laboratories around the world fuels this form of innovative scientific progress. Less frequently, scientific understanding advances dramatically, through the application of radically different approaches or interpretations that result in the creation of new paradigms or new scientific fields. This progress is revolutionary, for it transforms science by overthrowing entrenched paradigms and generating new ones. The research that comprises this latter form of scientific progress, here termed transformative research, is the focus of this report.

The challenge here is that transformative research opportunities appear less frequently and, depending on the methods and processes used for the selection of proposals, transformative proposals might find a harder time in a selection process. Transformative research might also be adversely affected by the incentives used for rewarding researchers, as professors involved in transformative projects, that might take longer to show results, might be bypassed in career progression processes.

In Brazil, the São Paulo Research Foundation (FAPESP) has been working to foster high intellectual impact research. This has been done by emphasizing programs for funding long-term projects (5 to 11 years) by fostering international collaborations and long-term industrial cooperation, and by requiring universities to offer institutional support to the Principal Investigators (PIs) and their projects. In Brazil, unlike what happens in most countries, funding agencies contract the projects directly with the PIs. The reasons for this relate to two facts. First, historically, back in the 1960s it was in the interest of the development of a merit-based science system to award funds directly to the investigators to single them out within their institutions bypassing the non-meritocratic power-structure in the universities, thus making sure the funds would get to the right persons. Secondly, due to arcane legislation regulating the use of public funds, contracting with the PIs removes some hurdles. As the values of the contracts increased, the time burden on the PIs also increased. Thus, having institutional support through a Grants Management Office became essential to allow PIs to direct their time to science and training of students.

Translational research

Another category that appeared in the last 20 years is Translational Research, mostly used in the Health Sciences. This one belongs mostly to the economic, and the societal, impact dimensions I outlined above. The definition given by the NIH National Center for Advancing Translational Science specifies Translation and Translational Science as (NIH National Center for Advancing Translational Science, 2015):

1. **Translation** — The process of turning observations in the laboratory, clinic and community into interventions that improve the health of individuals and the public — from diagnostics and therapeutics to medical procedures and behavioural changes.
2. **Translational Science** — The field of investigation focused on understanding the scientific and operational principles underlying each step of the translational process.

In the U.K., the Medical Research Council (MRC) uses a slightly different definition (MRC, 2015):

- **Translation** is the principle of turning fundamental discoveries into improvements in human health and economic benefit. MRC's translational aims — to drive innovation, speed up the transfer of the best ideas into new interventions, and improve the return on investment in fundamental research — and objectives are outlined in the MRC Strategic plan.

In both cases, it is clear that the focus is on applications of science to improve human health. It is striking that both definitions are unidirectional, from fundamental (or laboratory, clinic) discoveries to the patients or the public — from bench-to-bedside is a common buzzword. The possibility of motivating basic research from the needs of the patient/public — or doubling back from the bed-to-the-bench, does not appear emphasized, even though it has been raised by prominent scientists (Ledfort, 2008). That might have happened because the origin of the translational idea seems to have been affected by the consideration that NIH had been lending too much support to Basic Research (Butler, 2008). It should be noted that, regardless of the formal definitions, several research centres around the world are using the concept of "bench-to-bedside-and-back" to redefine the way they connect, bi-directionally, basic research to applications in the health sciences.

Research applied to societal needs

A generalization of the concepts behind Translational Research brings us to "Research applied to societal needs", which would describe the bi-directional connection between Basic research and societal needs. This is an encompassing category that can include any field of knowledge, from Anthropology to Zoology. It includes, of course, Environmental Science and there are several international efforts geared towards connecting the community in the social sciences to the physical and life sciences communities in topics related to global climate change (or global change, in the broader version). Sustainability is also a topic with growing relevance.

Curiosity-driven research

This is a favourite of academic researchers. More important, there is a breadth of works demonstrating how curiosity-driven research brought essential contributions to the stock of knowledge, leading to several instances of innovation and creation of benefits for society. Lasers, semiconductors, atomic physics and nuclear energy, modern biotechnology, are some of the examples that come to mind (Braben, 2004).

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Many times, curiosity-driven research is a favourite target of politicians and the public, when they want to criticize universities for being disconnected from the public interest. In many ways, curiosity-driven research is a twin of academic freedom, so important for the advancement of knowledge. Interestingly enough, curiosity-driven is not a quality that implies the uselessness of the research. It assumes only that the investigator chooses the theme or topic. Investigators choose themes and topics today taking into account the chances they have for obtaining the necessary funding to perform the research. At the same time, researchers many times want to create ideas relevant for society that will be recognized as such.

I do not believe anyone would defend the idea that there should be absolutely no support for curiosity-driven research[1]. The trouble comes when deciding about supporting research with taxpayer money, as the decision translates into defining how much societal needs should define research topics and how much should be left for the researchers to choose, according to their qualification and curiosity.

In the heated debate, most times the first line of defence for curiosity-driven research is to argue that discoveries will lead to economic development (or to curing diseases, or making the poor richer) in due time. Flexner used this argument in his exchange with Eastman. It might work sometimes, but this argument leaves out a large and relevant set of knowledge that might never be translated into wealth. Think of what is learned from studying philosophy, the humanities, astrophysics or particle physics. It seems difficult to make an argument that we need (or want) to learn the age of the universe because this knowledge will bring economic development. Some things must be learned just to make humankind wiser, and university research is (also) about this. Some might argue that it should be mostly about this.

HOW THE RESEARCH IS DONE

University-industry collaborative research

The collaboration in research between universities and industry has been recognized for some time as desirable for both organizations and potentially beneficial for the economy. Industry can use university research to mitigate scientific risks, to have access to highly qualified researchers and sophisticated research facilities, and to have privileged access to students and post-doctoral

1. There might be exceptions to this. For example, the then Governor of California, Ronald Reagan, famously said in 1967, “There are certain intellectual luxuries that perhaps we could do without”… [Taxpayers] “should not be subsidizing intellectual curiosity.” (Bennet, 2015)

fellows that can be hired in the future. Universities look for joint research with industry as it brings research funds and creates a visible contribution to the economy. University researchers often value the scientific challenges they can find in problems brought by industry.

In the North the intensity of interaction can be measured in terms of the relative participation of industry funds in the support of research. In the U.S. this percentage has been between 5% and 7% in recent years. Among OECD countries, the participation of the business sector funds in the total university research expenditure (OECD, n.d.) ranges between 2% and 10%, with Germany being an outlier at 14%.

In the South there is not much information, but recent data for the state of State of São Paulo, Brazil, shows a percentage around 5%. A relevant difficulty in the South is that industry does not have a strong tradition of having internal R&D. In Brazil, for example, for some time, there was an illusion that universities would be the R&D labs that industry did not have. After a few successes and many more failures, the three sides learned that there is R&D that must be performed in industrial R&D labs, there is research that fits well for university labs, and there might be some smaller part that might be performed by both. Recent legislation in Brazil, passed in 2004, created many incentives for joint university-industry research, and facilitated the licensing of IP created with taxpayers' money to the private sector.

University research and start-up companies

Start-up companies are another way in which university research can be translated to economic and social benefits. A few universities in the world are well known for their successes in this endeavour, and many more work hard to facilitate their occurrence, stimulated by the successful examples. In South America start-up creation is more and more frequently mentioned as an important goal, but few universities can display large numbers, either in the quantity of companies, or in the size of the larger ones. An especially successful university in the region is the University of Campinas (Unicamp), one of the three state universities in the State of São Paulo. Unicamp displays a list of 254 start-ups initiated by its students or professors in the last 25 years that sustain more than 16,000 jobs. Some of these became international companies in software, photonics and optical communications. Around the Aeronautics Technology Institute, in São José dos Campos, again in the state of São Paulo, a sizable cluster of airspace and defence companies has developed since the 1960s, the main one being Embraer, which is the third largest aircraft manufacturer in the world today.

SOCIETY EXPECTS MORE ECONOMIC AND SOCIETAL IMPACT FROM UNIVERSITY RESEARCH

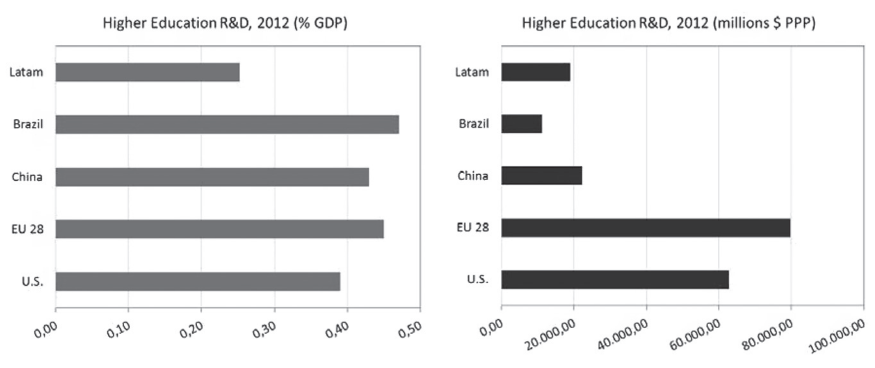
The message is clear: society continues to expect intellectual impact from university research, but now society has added to the charge more economic and societal impact. On top of this, it is also fundamental to consider that the value of scientific research includes not only economic and social impact, but also intellectual or cultural (knowledge that makes humankind wiser).

Research in higher education represents an important part of the R&D expenditures in the world (Figure 2) at a value above $PPP 200 billion in 2012.

Universities have been listening to the message and acting accordingly. A major challenge is how to listen and use society's expectations for more and faster impact while avoiding the trap of short-termism for research objectives. Relevant portions of society forget that the technology achievements of today occur because there was a lot of patient and continuous effort towards discovery in the past. This is a point well analysed in Mariana Mazzucato's *The Entrepreneurial State* (Mazzucato, 2013) in a parallel situation: the role of the state in creating or subsidizing the creation of knowledge that involves high enough risk.

In the Northern Hemisphere, it is easy to notice that universities are directing their research strategies towards Pasteur's Quadrant (Figure 1). An important part of the challenge seems to be how to figure out a way to give larger weight to use considerations, while still fostering the curiosity-driven concept or the value of fundamental research. An illustration of this behaviour is the growth in the quantity of new problem-oriented research centres created in universities in the last 10 years, as compared to the previous period.

Figure 3: Dimension of higher education research expenditures in selected regions/countries, as a percentage of regional GDP and in $PPP (values for Latam region estimated by author).



In the South there are some differences worth mentioning. Universities and their communities often lack conviction about their commitment to advancing knowledge and educating students. On the other hand, governments (and society) are quick, especially in times of scarce resources, to reach the conclusion that excellence is a luxury we perhaps can do without, to paraphrase Ronald Reagan. That applies to excellence in education and in research. In Brazil there is an interesting cyclical evolution around the year: when the international university rankings appear, society criticizes universities for not being excellent enough as Brazil appears with few names among the best 200. Then comes the season when the university entrance exams happen, when society criticizes the universities for being too demanding on excellence, requiring high qualifications to approve candidates and leading to the exclusion of those who have not had access to good middle education. Then someone in the media or government will criticize the high expenditure per student in the public universities (which are the ones that have research activities in Brazil). Then, after a few weeks, the same government (but another department) will criticize universities for not graduating enough engineers and other STEM that are necessary to maintain the competitiveness of the aircraft industry, or agriculture production, or energy generation. In doing that, they forget that, to a large extent, the cost of educating internationally competitive professionals is not set by how much money one wants to spend but by an international standard of excellence and quality.

CONCLUSION — THE SEARCH FOR MORE IMPACT AFFECTS AND IS AFFECTED BY FUNDING AGENCIES TOO

Finally, universities can and have been taking action to connect investigator-initiated research to impactful applications and applied research, while striving to maintain their fundamental contribution to increasing the stock of fundamental knowledge. It must be added that the success of the initiatives depends also on having access to research funds provided externally. Achieving all these goals might be impossible if government agencies direct most of their funds to short-term applied research. It must be remembered that the same kind of pressure that afflicts universities in this matter affects government research funders. For this reason, it is essential that research-funding agencies strive to maintain a balanced portfolio of programs that supports (GRC, 2015):

- Basic research and applied research
- Curiosity-driven and mission (or use)-oriented research
- Research executed by individual investigators and centres of excellence
- Non-thematic and priority areas.

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