MOOC Scientific Humanities

Bruno Latour, 2013
With Donato Ricci, Michael Flower, Maxime Crepel, Paul Girard
A product of the médialab of Sciences Po

Recomposed
Michael Flower, 2020

Teaser for the course

Suppose you are a student alerted by a tweet about the latest report by the United Nations body called the IPCC on the speed of "global warming" and that, at a family party, your uncle tells you that you should say "climate change" not "global warming" and that climatology is a scientific discipline thoroughly "polluted" by the "political views" of "the enemies of free enterprise". What do you do? One way is to lose any confidence in the authority of science — or in your uncle's sanity. The other solution is to begin to learn how scientific knowledge is produced and through what sorts of processes it achieves a type of certainty essential for the evolution of political debates. To do so, you will have to dive into an ocean of news, reports, opinions, scientific articles and disputes. But before diving you need some equipment.

Don't panic. This equipment is what the course will provide you with. We are going to offer you the opportunity to utilize a blog in ways that will help you make up your mind about controversial matters. In our view, this is one of the many ways to regain some confidence in the authority of science — and to conclude family parties without punching your uncle in the nose! You have to become well versed in "scientific humanities".

Usually the word "humanities" means the interpretation of the literary and artistic traditions. "Scientific humanities" means the extension of those interpretative skills to the discoveries made by science and to the technical innovations that define a large part of our daily world. It is the only way to overcome what is often called the "two-cultures" divide: science on one side; literature on the other. We need to equip future citizens with the means to be at ease with many issues that straddle the distinctions between science, morality, politics and society. Such interpretative skills are especially important when dealing with ecological issues.

During six of eight sequences, you will learn

a) the basics of the field called "science and technology studies", a vast corpus of literature developed over the last forty years to give a realistic description of knowledge production;

b) how to handle the flood of different opinions about contentious issues and order the various positions by using the tools now available through digital media; and

c) how to comment on those different pieces of news in a more articulated way through a specifically designed blog.

The remaining two sequences (five and eight) are set aside for Bruno Latour's video commentaries on a small selection of student-investigated controversies.

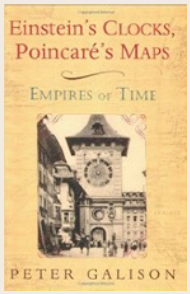
The course is designed for undergraduates but since the topic of scientific humanities is not widely known, it will be of interest for graduates and for the general public as well. Although it does not require a degree in science and technology, it will be of interest to scientists, engineers and physicians who will apprehend their traditional subject matters in a very different light. For those without any advanced knowledge in science, it will be a good occasion to become familiar with what is now an essential part of their culture.

Today, no one can afford the luxury of ignoring how science and society collaborate to mold our common world.

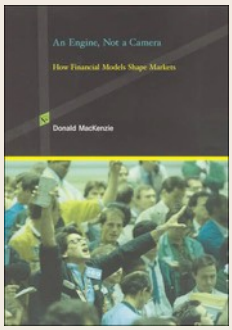
Sequence 1: How to patrol the borderline between science and politics?
Sequence 2: How to find one's way in the scientific literature?
Sequence 3: How to handle technical innovations?
Sequence 4: How to deal with controversies?
Sequence 5: Feedback on controversy blogs done by MOOC students.
Sequence 6: How to understand the shifting nature of the natural world?
Sequence 7: How to become a citizen in the public life of science and technology?
Sequence 8: More feedback on student blogs; concluding remarks.

What are Scientific Humanities?

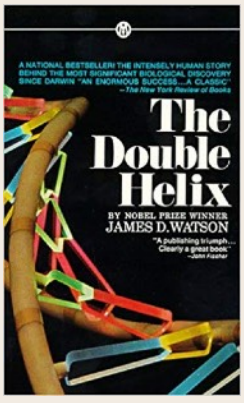
Since this is not a well-bounded field, you will likely come to understand what it is only at the end of the class! In the meantime it is probably best to define it by a few examples. I have chosen them to give you an idea of the range of topics we are going to deal with.



Suppose you have always had trouble understanding the importance of Einstein's relativity theory, and that you learn, by reading a marvelous book on his early days as a patent officer in Bern, Switzerland, that the Patent Office had to review dozens of "time machine" inventions designed to coordinate the clocks of the many railway companies sprouting up throughout Europe. Suddenly, everything falls into place: what had appeared as a terribly abstract argument was given flesh and blood. Even abstractions need a material ecosystem. **This is the scientific humanities**. (Peter Galison. *Einstein's Clocks, Poincarés's Maps*. New York: Norton and Company, 2003.)



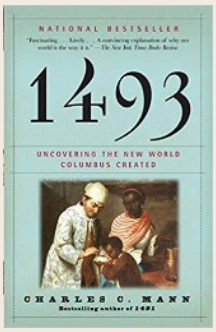
Suppose your parents have lost their house in the recent financial crisis and that you realize, by reading a book on the Black-Scholes equation for pricing "futures" that this equation, before being embedded into computer models and banking organizations, was manufactured by specific people in a highly specific situation. That far from being a "camera" recording a state of affairs, it has been a powerful "engine" for allowing bankers to take even more risks than they would have taken without this tiny piece of mathematics. Suddenly, what had seemed to you the inevitable thrust of a free market became one of the highly contingent products of a link between mathematics and banking that you might learn to resist. **This is the scientific humanities**. (Donald MacKenzie. *An Engine, Not a Camera: Finance Theory and the Making of Markets*. Cambridge, Mass: MIT Press, 2006.)



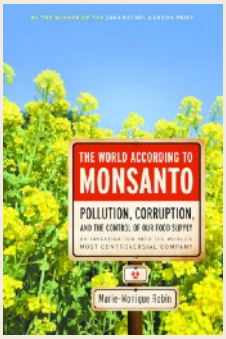
Suppose that after a class on molecular biology your teacher had the good sense to direct you to the reading of James Watson's The Double Helix: what a delight to read from the mouth of the discoverer himself how this most important discovery had been made. Even if the story is a bit self-serving, even if it is not fully accurate historically, suddenly what had been for you a result to learn for an exam ("A pairs with T; G pairs with C"), became one episode of an adventure, an adventure that continues today and that you might want to pursue yourself. The beautiful excitement of science and the sheer beauty of the double helix itself strike you to the full. **This is the scientific humanities**. (James Watson. *The Double Helix*. New York: Paperback Mentor Book, 1968.)

Suppose that you try building a small appliance using your own hands and the material around you, let's say a vacuum cleaner or an electric toaster. And that you realize that you need months of travel, a lot of learning, much sweat and a great deal of money to end up with a horrible kludge that works for a few second before exploding! Then you would have realized that what an "object" needs to exist as a reliable and inexpensive appliance is a whole ecosystem of industries, engineers, marketers and stores. **This is the scientific humanities**. (Thomas Thwaites. *The Toaster Project - or a Heroic Attempt to Build a Simple Electric Appliance from Scratch*. New York: Princeton Architectural Press, 2011.)

Suppose that you decide to eat only "local" food and that you realize, reading a book on the history of the spread and displacement of plants and people, that this enterprise has been made extraordinarily difficult since at least 1492. That the very notion of "native" plants (as well as that of "native" people) depends on the time frame you choose, and that if you begin to take a larger unit of time what you observe is a frenzied agitation of all the components of what had appeared, before you started this search, as a stable and immutable landscape. **This is the scientific humanities**. (Charles C. Mann. *1493. Uncovering the New World Columbus Created*. New York: Vintage Books, 2011.)



Suppose you are a young Indian student and that you worry about the controversies raging in your local press about GMO modified eggplant, rice or cotton that your parents want to grow in their fields and that you feel, for some reason, should be resisted. It is crucially important to measure the relations of power between the various protagonists so that you know in what sort of science and politics imbroglio you are going to engage. How interesting to watch the documentary (even it is fairly one-sided) and read the book of a journalist who has done an inquiry on the power of Monsanto, the arch villain of so many controversies over the future of agriculture and food. **This is the scientific humanities**. (Marie-Monique Robin. *The World According to Monsanto. Pollution, Corruption and the Control of Our Food Supply*. [Translated by Georges Holoch]. New York: The New Press, 2012.)



Okay enough examples! Now you have to see for yourself, and if you want to have a good overview of the field of science studies out of which this course has grown, it is probably best that you get access to a reader. (Mario Biagioli, ed. *The Science Studies Reader*. London: Routledge, 1999.)

INTRO—SEQUENCE 1: HOW TO PATROL THE BORDERLINE BETWEEN SCIENCE AND POLITICS

[Intro videos: Part 1.1 and Part 1.2]

There exist two situations for which this course is of no use whatsoever. Situation one: you follow people who go on doing their business without ever using a piece of technology, without ever hesitating to think about the solidity of a piece of information that they need to make up their mind, without ever having to be confronted with experts who know more than they do about some state of affairs. Not a very realistic situation, I agree. Situation two: you encounter a piece of information about a state of affairs that has not been produced by anybody but that has come directly to you without any trace of its origin, no date, no indication of place, no trademark of any sort, just sitting there, in front of you, indisputable. Although it is not as commonly recognized, I think you will easily agree that such a situation is just as unrealistic as the first.

If you look around, you will find that most daily encounters require that you use, at some point, a piece of technology, that you stop to think about the solidity of some piece of information and that you meet experts. And you will notice that those experts, who claim that they know more than you, will, when they are challenged, direct your attention to where, when and how this piece of information has been produced. In other words, if we want to be a bit realistic as to how we go about managing our daily business, we have to recognize: one, that we are constantly dealing with techniques and very often have to rely on some expert knowledge; and, two, that this knowledge depends on people and places that appear to play a crucial role in its solidity, robustness and accuracy.

You find this obvious, even trite? Well maybe so, but you will soon realize that it is very difficult to offer a realistic description of such a trivial state of affairs. Why? Because we seem to suffer from a division of intellectual labor: if you have learned history, social sciences, literature, law, art or any branch of what is called "the humanities", I am sure you have learned a lot of things, but not necessarily about how technology and science have interfered in all those various fields; conversely, if you have taken classes or degrees in engineering, computers, natural sciences or various applied trades, I am not sure that you will have learned a lot about when, where and by whom those elements of knowledge have been produced and what relations they entertain with history, literature, art, politics or social sciences.

If you are a doctor, how many classes on the history of medicine did you get? If you are a lawyer, how many classes were you offered on the laws of physics? If you are an engineer how much have you read in the social history of technology? If you are an accountant, what have you learned about the early philosophy of your discipline?

Whichever field you come from, chances are that you have realized that there exists a divide between those coming from "the letters" and those who come "from the sciences". And not only a divide, but often alas, some form of condescendence, even of spite against those of the other side: you might have been treated as a "illiterate nerd" by some bright literary scholar who, in turn, might have been treated as a "romantic prick" by some serious fellow from the mathematics department. If you have never encountered such reactions and never noticed this divide, you are very lucky and you don't need this course!

Those who need it are those who wish to bridge the gap between the two sides (what are often called "the two cultures") and to learn how to provide a more realistic description of our daily encounters with technology and science.

Such a course is not a substitute for the many classes in the humanities, nor it is a substitute for classes in the natural and the social sciences. Take as many of those as you can get. What we are offering you here is a highly specialized course on how to deal with nothing else but the interface between those various trades. And of course, the more you master them, the better.

One of the difficulties you are going to face is that this highly focused question — how are science and technology connected with the rest of our daily life? — will lead you, step by step, to many different sites you would have never visited without asking it. So, even though it is very specific question, it is also a very large one since, as you will soon painfully notice, there are very few situations that we will not have to redescribe in order: one, to underline the role of science and technology in molding them; and, two, to foreground the role of people and society in molding, in turn, those results of science and technology. The material is everywhere, what is missing is how to handle it.

Don't be afraid, we are going to help you in this double movement: how to focus your attention on the interface — it is often described under the label "STS" for "Science and Technology Studies" — and how to enlarge your vision by asking you to follow a very practical procedure. The procedure will provide the empirical material that you will have to deal with according to the concepts we will also provide you with.

Let me start with the most important, namely the practical procedure. We are going to ask you to maintain a blog devoted to the class. This blog will bear on a small segment of your life: what you have noticed between the beginning of the class and its end that is linked to the questions of the class, much as you would do if you had a private notebook. We are not asking you to learn about the whole history of science, the philosophy of technology, the foundation of physics or the nature of evolutionary theory. No, we just want you to record, as accurately as possible, what is happening around you that provides some information about the ways science and technology intersect with the many events of your daily life.

Be assured that you are not going to lack material: after a few weeks, your blog will overflow with too many posts!

Now, don't think it is too easy either. Maintaining a blog will simply allow you to gather the primary material. The next procedure spells out what to do with this material. As I said, what we are going to teach you will oblige you to constantly cross the often very deep divide between "the two cultures", those of the "humanities" and those of "science". For such a crisscrossing there is unfortunately no widely shared set of expert methods. We will often have to fight against common sense as well as deeply entrenched reactions. This is what makes this course challenging, sometimes controversial, but on the whole very exciting!

Fortunately we will rely on a large body of work coming from the STS field. For forty years now, historians, sociologists, economists, psychologists, archeologists, anthropologists, political scientists, administrators and many concerned scientists together with some philosophers, have offered many alternative descriptions of how science and technology are produced. Collectively, they have offered a very different view of the many ways in which the two cultures are related. So, we are not going to ask you to reinvent the wheel. In each sequence, you will be directed to some of the best examples of this literature.

However, this is not a course in STS or what is often called "science studies" either. This course offers a primer that should later help you to read this literature and to learn more about this field. This is why I prefer to use the word "scientific humanities". What we need to teach you is a set of interpretative skills — the main resource of the humanities — that have a bearing on science and technology — this is what means here the adjective "scientific". It does not mean that we wish to render the fields of humanities more "scientific" in the sense of being entirely explained by the natural sciences, but, on the contrary, to help you develop a set of systematic, rigorous, methodical critical tools to handle the many instances where science and technology have impacted your life and the life of those you will follow through your blog.

This first sequence will show you how to get started. First, I will give you two historical examples so as to highlight the two main concepts we need as we go along, that of translation and composition. Then, we will explain how to design your blog posts and will provide you with examples so that you see how it works. Nothing really complicated, even though it requires a good deal of attention and a readiness on your part to suspend many clichés about science as well as about society. My hope is that you gain a new respect for the ways science and society really work.

INTRO—SEQUENCE 2: HOW TO FIND ONE'S WAY IN THE SCIENTIFIC LITERATURE
[Intro videos: Part 2.1 and Part 2.2]

I am sure that you have heard about the great French philosopher René Descartes who lived in the 17 th century. One of his sayings has become so famous that it has been turned into an icon of modern philosophy: "I think, therefore I am" — in Latin (the language of scholarship at the time, just like English is today): "cogito, ergo sum".

Well, there is an amusing as well as intriguing paradox in this sentence, because Descartes lived just at the time when a scientific community began to get organized throughout the whole of Europe (by the way the word "scientist" did not exist at the time, they called themselves "natural philosophers"). So when he says: "I think therefore I know for certain that I am", he is also implying something exactly opposite: "We, the new emerging community of philosophers and experimenters, are thinking collectively, trying to ascertain, through experiments, a whole set of new claims about what the world is made up of". Hence the enigmatic motto we have chosen for this class: "*cogitamus ergo civitas sumus*". Not "I think", but "we think" and not "therefore I am", but "therefore we form a group of citizens sharing more or less the same values and having more or less the same responsibilities in checking each others claims".

In this second sequence, you are going to learn how to visit this new city, this new assembly, whose work is able to produce new types of certainties. Not by portraying scientists thinking alone, secluded in some ivory tower, but, on the contrary, by multiplying their connections with a lot of other people and a lot of other institutions and instruments just as we have seen last week. You will have to portray what is often called an "epistemic community" or a "thought collective".

If you have followed the instructions we gave you in sequence 1, your blog must already contain examples of this collective process of ascertaining claims about what the world is like. You most probably have recorded instances of arguments that are, in effect, just so many claims for the existence of phenomena invisible until now. For instance, new drugs that have dangerous side effects, or new planets that have been discovered around other stars, or a new study about the link between poverty and cognitive abilities, and so on and so forth.

The reason that we insist on your following "new" claims is that it will be easier than with older ones for you to discover the collective process that might, in the end, ascertain them or, on the contrary, dissolve them out of existence. Once they are entrenched into the stock of ascertained knowledge, it is much more difficult to detect where they came from.

If I ask you what is the atomic composition of water, chance is that you answer, unhesitatingly, "H20". This statement is certainly accurate, but if I then ask you: "Show me the proof of this statement", you will be at a loss, because it is so well ascertained that no one bothers anymore to establish it through a publication, a blog, a tweet or a newspaper. It is settled. And if I insist, you will shrug it off and say "Everyone knows that", "Look for yourself in any encyclopedia" or even more bluntly: "It's part of nature". In effect, the statement has been, to use an expression from the social sciences, fully "naturalized". It is part of the landscape. All traces of its production have vanished.

Which is great. It means you don't have to bother proving it. You may safely use this statement to predict another one. You could say, for instance: "Since the atomic composition of water is H20, it should be possible to invent a process that separates hydrogen from oxygen". In such a claim, the first part of the sentence, what is called the "premise", is more certain than what comes next (by the way, hydrolysis is still a very hot topic). Your interlocutor is asked to concentrate on the latter part of the claim and not on the former. You have built a sort of downhill slope directing the attention and then the movement of those you address from the nature of water to what you could do with this knowledge.

We all live in such a highly differentiated landscape of arguments, constantly negotiating our ways through through channels and valleys, across plains, and carefully up and down cliffs. That's the geography we have to become familiar with by learning to map it. [carte du tender]

As you have noticed in your blogs, we are all bombarded, every day, by people who make claims that are based on premises that result from them having taken a prior statement for granted. Or, this is where the problem lies, that they say, are fully naturalized. Why is it a problem? Because, when "people say" such and such a statement has to be taken for granted, is it really so? Are we considering what exists in nature, or what is said, by some people, about what exists in nature? In other words, is it a statement or a fact?

This is such a big philosophical, ethical and practical problem that there is no way to tackle it directly (we will come back to that big problem in sequence 4). For now, we are going to tackle it by taking a very simple route: we will use nothing more complicated than quotation marks!

There is the joke that you may easily recognize someone from the humanities because they constantly make this gesture with both hands: they semaphore "scare quotes"! Well, you should not be scared nor should you spare quotation marks. Quotations are a great way to protect a statement against too quick a naturalization. That is a great instrument of critique. It is a great tool of the humanities and it is precisely by using them a lot that we make ourselves human and scientific!. And once

you have learned when and where you multiply them then you will understand why, when you remove them, it is for good.

For this week you need to learn no other skill than that of comic book writers when they draw bubbles around a statement and put it in someone's mouth. As soon as you do this, a statement that was floating around becomes grounded. Then nothing will stop you from drawing the rest of the scene. It is uttered by someone in a story that has many characters, a whole décor, and that has a beginning and an end. You will quickly learn to reconstruct where the statement comes from and to specify the profession, setting, and equipment of those who have launched it. You have in effect sourced the origin of the claim. Just as any journalist would do.

But then, you will soon realize, this is going to lead you much further. First, you will be led step by step to different types of media. If you have started with a post in a blog, you might have been referred to a newspaper, and from there to a report, from which, most probably, you will be pointed toward what is called the "scientific literature". If there is no path leading you from trace to trace, along such a paper trail, chances are you are dealing with one of those rumors that can be neither proved or disproved.. Abandon it. It is probably just someone's opinion. There is no way to build any cognitive thinking around that one. Choose another example.

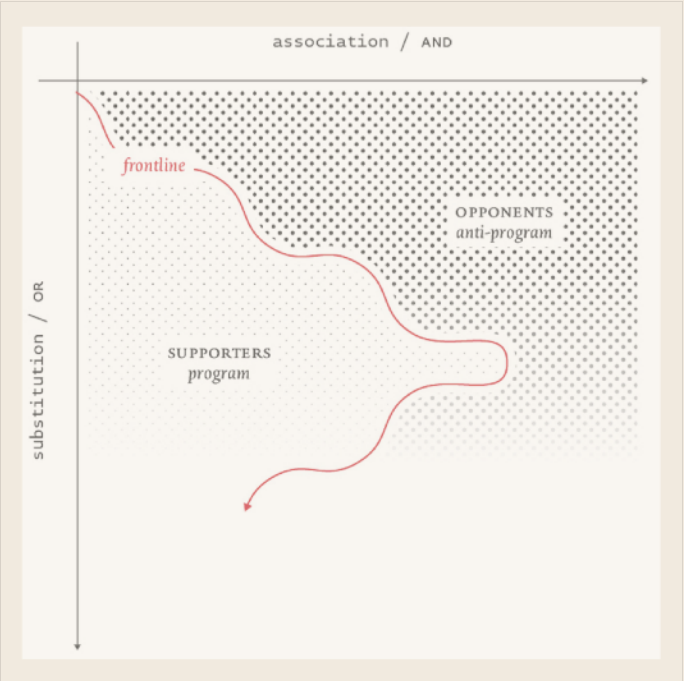
But once you reach a more esoteric document, don't panic. There is no way to get used to scientific humanities without learning how to find your way through scientific literature. It is the most interesting part of your trip because from the literature you will be led, first to laboratories and research centers, and, from there, to the experimental scenes that form the most fascinating and convincing parts of the papers you have chosen as the source of your little inquiry. Starting from a floating statement, you will have come to the flesh and bone of scientific practice.

The idea of this sequence is that you will respect the certainty of a claim much better once you have become acquainted with how it is produced. At first, you might be horrified to see how difficult it is for a statement to reach the state of an established and indisputable fact. So many intermediary steps, so many precautions to take, so many people involved in discussing it, so much money to spend, so many instruments to assemble. But then you will realize that it is precisely thanks to this collective process of slow and highly mediated fabrication that there are, in the end, solid and robust facts you may safely count on to find your way in the real world. The etymology of the word "fact" is tricky as well as enlightening: it may mean fabricated thus false, or fabricated thus solid. It is the second path we invite you to follow. *Cogitamus* not *cogito*.

How to follow a floating statement

To talk about science, I go about things the same way. I don't begin by explaining the chemical composition of air, by showing the three-dimensional shape of DNA, or by drawing up a list of elementary particles. We're not in class—well, we are, but we're not in a science class, we're in a humanities course. So where do we start? If I were bold enough, I'd say, with Saint John: "In the beginning was the word." And only then science. Let us say, less grandiosely, that I'm going to ask students to start with discourse, with those great swathes of language in which we've been engulfed since our childhood, that continual bombardment of words that attracts our attention to one aspect of the world or another and to which labels of a sort are attached, which guarantee the greater or lesser authority of these words. That is the first phenomenon with which they must agree to grapple. It doesn't bother me that students are somewhat at sea at first. It does them nothing but good. If they want to comprehend science, they must begin with those great waves of words, more or less disconnected, more or less regular, that buffet them. And then they learn to swim.

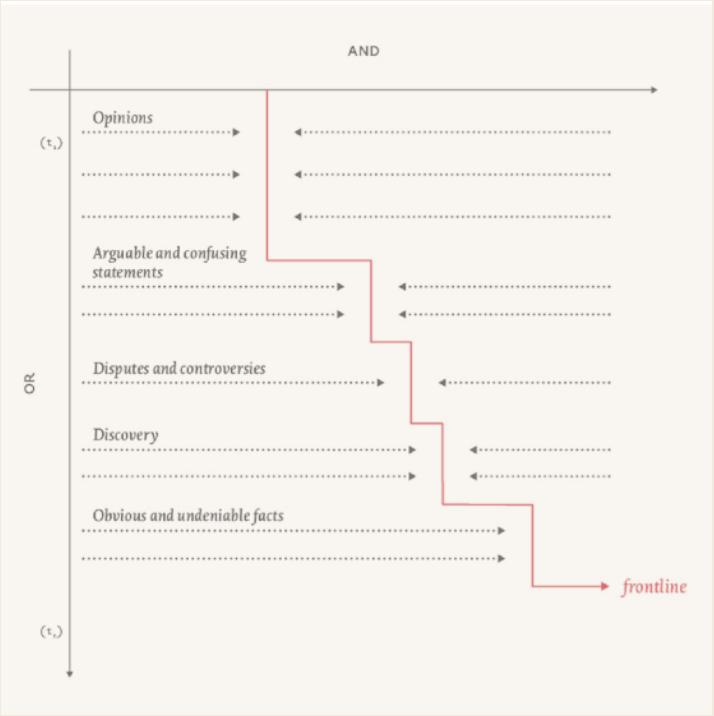
As you will see in Sequence 3 the particularity of the technological detour is that it disappears once the translation is effective and that it gives the impression of a uniform course of action composed of only a single stage, even though, in the case of a breakdown, you realize it is made of thousands of diverse components. I told you that technology was as a result naturalized as well, that it too was invisible. If we're not careful, the risk is that science will turn out to be the same. You'll tell me that's just fine and that, the more invisible it becomes by becoming indistinguishable from the world, the greater its authority and the less we'll have to modalize its utterances. Perhaps, but if I'm to believe our blogs, we often see conflicts of authority arising first within the sciences and then between science and politics. If I don't succeed in equipping students to follow every variation, they'll really be at sea, and it will always be impossible for us to untangle or arbitrate these conflicts, since one of their sources, science, will remain invisible.



You can even reuse the diagram I provided to show the front line that, in my view, defines also any technological project (provided it is taken in its movement and not frozen into an object). It can also be used to follow the movement by which an utterance undergoes a transformation in the heat of controversy.

Once again there's the composition or association dimension (AND) and the detour and substitution dimension (OR). And once again, there are the "pros" and the "cons," which

support or undermine an utterance, and also the front line that marks the work of translation: the aspect of an utterance that has to be modified so that it will succeed in convincing those who are opposed to it. Here again, one gains in associations (in conviction) only by "paying" the cost in transformations (fresh starts, detours). It is after being greatly transformed (for the length of the OR dimension) that it can finally be accepted (that is the AND dimension). But nothing is definitive: there are technical objects that get rusty and utterances that fall into disuse. To exist is always to stand on that front line. Science cannot keep itself alive solely by the force of inertia any more than technology can. Pace Pontius Pilate, what is written is not always written.

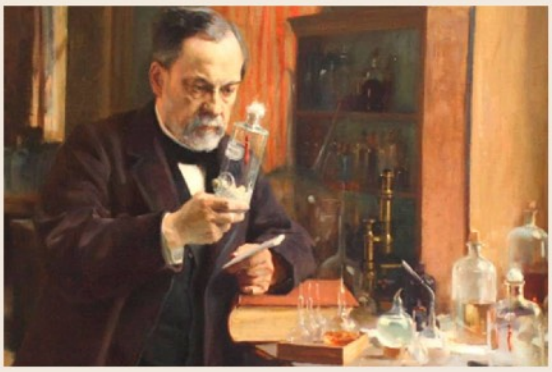


The only real utility of this diagram is to serve as a reminder that what is ordinarily called an unquestionable utterance is only the final stage in a controversy and not at all its beginning. In further generalizing the previous diagram, we perceive without difficulty that the differences in nature between "false" and "true" utterances, rumors and discoveries, disputable arguments and indisputable facts correspond to successive stages in the series of transformations an utterance must undergo in order to thread its way through the "pros" and the "cons". To take the two extremes, fact and opinion correspond to two moments in the controversy. In other words, the indisputable emerges from the disputed. We shall see the importance of that result in a moment.

What is remarkable about science is not only that disputes sometimes result in the indisputable but also that it is possible to follow from one end to the other how that result is reached—and therefore also why it is not always reached. In actuality, utterances marked with the seal of a scientific origin have something in common with good wines: thanks to the system of citations, they possess a sort of appellation d'origine controllée, a designation of controlled origin. (The new digital information technology has extended that privilege to utterances that would have previously been impossible to trace precisely, such as viewpoints, opinions, gossip, and rumors). I therefore ask students to avail themselves of citations as so many signposts and to trace a mainstream newspaper article step by step, back to the more esoteric scientific articles the journalist used. Fortunately, thanks to the instruments available on the Web, that exercise has become child's play (though it continues to be expensive for those not studying at a university with subscriptions to broad databases). One therefore moves easily from floating words to rooted words and gradually through that other labyrinth, that of scientific and technical information.

Making Proofs

Louis Pasteur and the Controversy Over Spontaneous Generation



As we go about finding our way in the scientific literature, we encounter data, diagrams, photographs and such, all pointing from the text to the laboratory or field site where instruments and other tools of the scientist's trade are found. Here Bruno Latour places us at the borderline between scientific text and laboratory as he introduces Louis Pasteur's experimental approach to the dispute over spontaneous generation.

To further appreciate the experimentalist's approach we can view two additional depictions. In 1974 the BBC produced a well-known series entitled *Microbes and Men*. Here is a short excerpt from that series wherein we see Pasteur at work, in discussions of experiments with colleagues, and lecturing to an audience about spontaneous generation. As part of the 1999 exhibition, Laboratorium, Bruno Latour was asked by Ulbrich Obrist (its curator) to stage a reenactment of Louis Pasteur's famous April 7, 1864 Sorbonne lecture on spontaneous generation (see the text of that lecture).

How to bring people back into science

When students get back to the source articles in that way, they are often surprised by a strange contradiction: they come upon objects that they initially find daunting but that very quickly reveal rich material for the bubble exercise. Since they often imagine that a scientific article has to be written in a neutral style by uncommitted authors speaking in a robotic voice, rather like Mr. Spock on Star Trek, what a surprise it is for them to see the authors of the real articles taking all kinds of precautions, criticizing their predecessors and themselves, mentioning their financing, their institutions, the difficulties they encountered, the fragile instruments by which they obtain their results and launch hypotheses, which others will later have to take up and, if possible, validate or invalidate.

Obviously, it takes a little effort to extract all these marks of interlocution from an article on the leading edge of research, but students are always struck by the quality of the data that can be obtained on following how an utterance becomes credible. Of course, within the time frame available to them, they can follow these vicissitudes for only a very small portion of their trajectory. But in becoming familiar with the situation of interlocution from which the utterances arise—in travelling upstream, as it were—they can better understand how these words undergo a transformation downstream, gradually losing their connections until they become impossible to distinguish a rumor from an obvious matter of common sense, or an indisputable fact. Try it yourself. As for me, I've always read scientific articles, not without some perversity, as real operas or suspense thrillers.

Scientific papers have authors

Utterances that had previously been floating now possess a proper name, are related to a profession and an institution, and have financing (the names of most of those who supported them are usually found at the end of the article); they are surrounded by colleagues (co-authors of articles or collaborators acknowledged in a note); they have opponents and supporters, either upstream from the article, taken as a starting point (those whose articles are criticized or confirmed, the references to which can be found in the notes —these are the cited articles), or downstream (those that, later on, and in other articles, which can be located in digital databases, confirm or invalidate their arguments—these are the citing articles). Unattached utterances have been replaced by a situation of interlocution that extends both upstream and downstream. All of this takes time to retrace but does not pose any problems.

All the same, the bubble exercise has only just begun. Although the benefit is not negligible, it remains inadequate, since we are, precisely, still within a situation of interlocution. The same thing could be found at the bar of the Café le Basile: human beings speaking to human beings. If we were to remain at that point, we would be reduced to chitchat, to the purely social. And we would therefore be in great danger of reducing the authority of an argument to the bigmouth who talks the loudest—as in barroom quarrels.

But there is something even more compelling about scientific articles, which is that they manage to add to the situation of interlocution other speakers, previously untalkative, who add their two cents' worth to what the humans are saying and, even more astonishing, to what the humans were claiming to assert about them. I say this as if it were speech at issue,

but actually we're in the realm of the written, or rather, of the inscribed. The most striking characteristic about scientific articles is that nothing is said in prose that does not refer to an inscription in the text itself, which the reader scrutinizes as he reads the text. You will almost always be able to recognize by that trait whether a text is scientific or not.

A new source of authority

What a formidable source of authority, since nothing will be asserted that is not guaranteed by a document displayed directly opposite what is being asserted and as close as possible to it. In newspapers and magazines, you will certainly find photos, sometimes documents, but they play the role of illustrations. When an article is scientific, however, it is not simply illustrated: it succeeds in mobilizing on the page itself the very thing of which it speaks. How do we know it's not merely an illustration? Because the inscriptions are connected to one another in a kind of domino effect, with each one slightly transforming the one before and the one after—a table will be reprised in an equation, a photograph in a diagram, a diagram in a schema, a schema in a model. As for the written text, it strives to record nothing that is not inscribed before the reader's eyes.

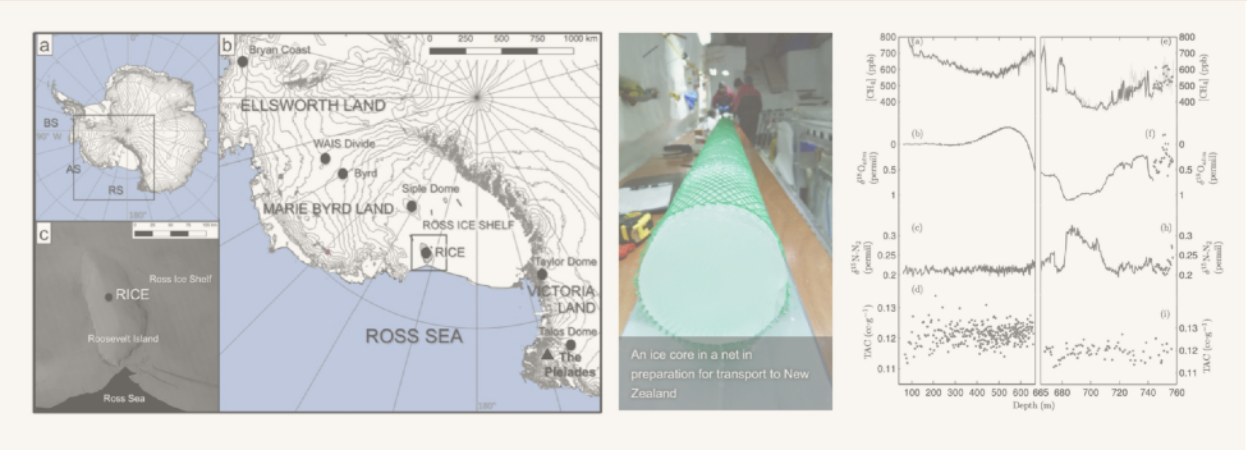
Inscription

So now there's a new layering effect, different from that of technology, but accomplishing the same prodigious feat of moving mountains: through a careful arrangement of the dominoes of inscription, it will be possible to guarantee every stage in the argument through a perceptive judgment on the reader's part, which will always have to do with elements simpler than what has to be proven. Students are sometimes astonished that an apparently complicated scientific article actually rests on inscriptions that are often extremely simple. Obviously, that simplicity comes at a high cost. It takes days, years of work to obtain these inscriptions. That is apparent in the captions, which sometimes take up a full page. The perceptive judgment, however, must be simple. Otherwise, the argument would be lost, since, in case of doubt about the commentary, it ought to be possible to resort to inspection at a glance. Whether it is statistical tables or equations, one sees what is said, one says what is seen.

I might now take a further step and, like Alice, step through the looking-glass of texts, to show where all these inscriptions really come from. We would then come upon laboratory instruments. And there, our bubble exercise would start to become realistic: we would really and truly have repeopled science. We would not only get away from chitchat, from the written text (prose), from the inscribed (inscriptions), we would also finally arrive in a three-dimensional world, places that are very particular, very rarefied, very well-equipped, very well-instrumented, very costly, very fragile as well, but inaccessible, places where I cannot take my students except through films. I love laboratories! I swear to you that my heart beats faster when I enter a laboratory, even for a minute, in any field whatever. There is nothing more exciting, nothing more moving. I quiver, I understand, I admire, I know. It is true that that's where I earned my spurs—not as a technician (I was a deplorable lab assistant) but as an ethnologist, and that it was there that I learned to love the sciences. In my own way, of course, but truly love. Yes, I believe I understand what the libido sciendi is. Every single time, I feel like Archimedes, naked, compelled to get out of his bathtub and exclaim: "Eureka! Give me a laboratory and I will move the world."

Mobilizing Antarctic Ice Cores

Michael Flower



The Roosevelt Island Climate Evolution (RICE) Project is a multi-nation undertaking that links many investigators, laboratories, and modes of physical and chemical analysis geared to the study of past, present and future changes of the Ross Ice Shelf. Key to the project is the drilling of ice cores at a site on Roosevelt Island that is surrounded by the Ross Ice Shelf, itself a major drainage pathway of the West Antarctica Ice Sheet. The intent of the study [as described in 2014 was] "to provide an annually resolved ice core record for the past 20,000 years" and thereby enable "the precise correlation between increasing air and ocean temperatures, and the velocity and characteristics of the ice shelf retreat, [providing] a unique opportunity to determine accurately the sensitivity of the Ross Ice Shelf to warming" [RICE Project website; see brief 2020 update in the block quote below]. Getting from the Antarctica site to the laboratory to published papers—and perhaps then to deliberations about public policy—is a long, arduous journey, a large part of that being the story of ice cores.

> The RICE project, a 9 nation collaboration, aims to determine the stability of the Ross Ice Shelf in a warming world, thus improving estimates of contributions of the West Antarctic Ice Sheet to future sea level rise. With a recently recovered 764 m (~2,500 ft) ice core, our team of scientists and students are using a variety of scientific techniques and models to reconstruct Antarctic/Southern Ocean climate conditions over the past 70,000 years and perhaps beyond. The RICE data will help to improve our understanding of drivers, thresholds, and feedback mechanism of ice sheet retreat and collapse. Furthermore, the records will allow us to assess and improve models which then are used to project future change.

Dr. Nancy Bertler (Antarctic Research Centre, Victoria University of Wellington, New Zealand) is Chief Scientist of the RICE Project. In the accompanying video Dr. Bertler describes the Project's aim, the ice core site, the drilling and processing of cores, their transport from Roosevelt Island to Scotts Base and on to New Zealand via ship. There sections of the ice core are analyzed.

As part of her introduction to the RICE Project Dr. Bertler identifies the major concerns it aims to address: the stability of the Western Antarctica ice sheets (0:25) and lack of knowledge

about the volume of water trapped as ice and how fast the Antarctic ice might melt. Gaining knowledge of the Ross Ice Shelf will help us better address these concerns and part of what is needed to accomplish that is frozen deep in the ice covering Roosevelt Island.

2:15 - Obtaining ice cores is a daunting task. A suitable site must be identified and a drilling station established; in this case tons of equipment, fuel and other supplies must be transported to the Island by plane. Living quarters and a drill tent must be built (2:45) and a work area beneath the tent must be carved out of the snow; the specially designed drilling platform and drill must be put in place (3:35). Then the drilling commences. Cores from deeper and deeper in the ice are retrieved: hour after hour,day after day throughout two four-month drilling seasons the work continues until more than 750 meters of ice core are obtained. A core that was once part of an uninterrupted layer of ice nearly a half-mile thick has been mobilized by Dr. Bertler and her team. The core is not only drawn from the ice; it is now available to be drawn into the ongoing studies of the question that motivated the RICE Project—what is the stability of the Western Antarctica ice sheets?

5:50 - A number of scientific questions can be put to the core. However, those questions are posed elsewhere—in Dr. Bertler's laboratory in New Zealand and in the laboratories of others who are part of the multi-nation research enterprise. The core has to be moved. Over the course of the drilling, the core has been sawn into 1 meter-long sections, bagged, carefully labeled and recorded, and stored in freezer chests that are also labeled. The core segments are transported by plane and then by ship to New Zealand, all the while kept below -18 degrees C so as to maintain the "integrity" of the "record" that will result from the further study of the ice core segments. The RICE Project scientists require not only that the cores be moved from Antarctica but also that they be moved unchanged. Dr. Bertler and her colleagues want to study a bit of Antarctica as-it-was over thousands of years but to do so in a laboratory more than two thousand miles from Antarctica.

6:24 - The scene changes dramatically once the boxes of core segments are safely stored in a -35 degree C freezer at the New Zealand Ice Core Research Facility. Far away from the mercurial weather and cold temperatures of Antarctica the core segments can be studied in the relative comfort of a -18 degree C work freezer! The "integrity" of core segments that was so important to maintain during transport from Antarctica is assured in the laboratory, even as that requires the bundling up the scientists and technicians so they can keep warm.

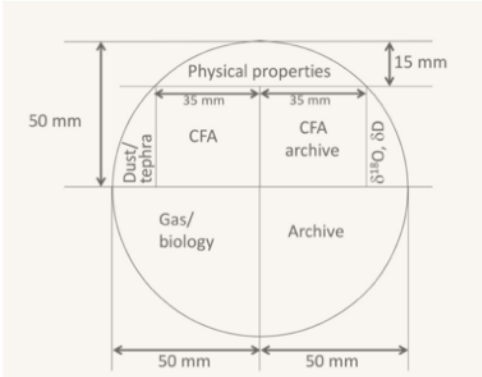


Figure 2. The cutting plan for the RICE main core included two CFA sticks of size 35 × 35 mm.

7:15 - Not only to keep warm but also to keep the ice core segments from being contaminated, Dr. Bertler and her colleagues work in white suits and wear gloves when handling the cores. And during the melting of the core segments the "melt" from the pristine inner portion of the core is kept separate from that of outside. Here is "integrity" of a different sort. Changes in the composition of the core can be expected to be small and thus contamination must be guarded against.

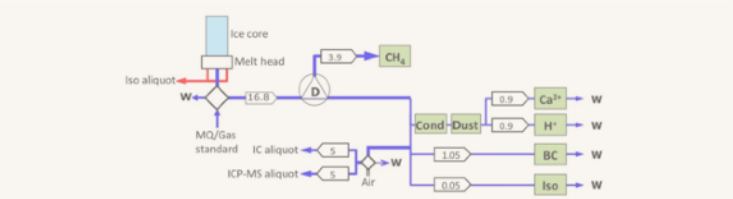
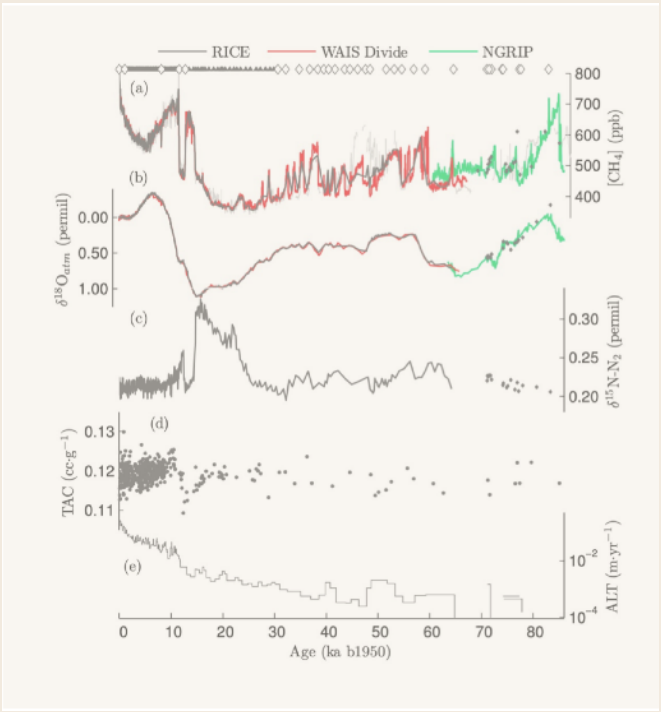


Figure 3. The RICE CFA setup. A 1 m long ice-core rod (light blue) is placed on a melt head, which separates meltwater from the pristine inner part of the core from that of the more contaminated outer rim. Meltwater from the outer stream (red) is used for discrete measurements of water isotopes, while the meltwater stream from the inner core section (dark blue) passes through a debubbler (D), which separates air from the meltwater. The air composition is analyzed for methane concentration, while the meltwater stream is channeled to various analytical instruments for continuous impurity analysis of dust, conductivity (cond), calcium (Ca^{2+}), acidity (H^+), black carbon (BC), and water isotopes (Iso), as well as collected in vials for discrete aliquot sampling by IC and ICP-MS. W denotes wastewater. Diamonds represent injection valves used for introduction of air or water standards when the melter system is not in use. Arrow boxes indicate liquid flow rates in mL min^{-1}. Green boxes represent analytical instruments.

7:50 - As the melt proceeds a drop by drop record of the core segment is produced—and for a number of different characteristics of particulate matter, chemical composition, and of the air trapped in bubbles in the ice many, many years in the past. We see carbon monoxide and methane content displayed (8:20), the results of the water flow being fractionated into tubes (8:35), and yet another display of raw data from another of the assays (8:39). And of course the results of these various assays can be assigned to particular positions along the core segment—and thus to particular times in the past.

Here we must add to the original MOOC version of this ice mobilization story now that the RICE Project data are being published. In this last schematic we see time series data extending 83,000 years into the past. We see the past represented, knowing that integrity of the ice cores and the carefully observed procedures at every step of the way from Antarctica to the pages of the journal article have been duly noted. If need be we can make our way back from this data portrayal to the place and time of the coring of the Antarctic ice upon which the data rest.



Near the end of the presentation we have linked to, Dr. Bertler says that each of the drops of the melted core segments is "precious", "contributing vital information on how Antarctica will respond in a warming world." It is important for us to appreciate the many steps and the various expenditures of labor and resources that are necessary to link ice that is thousands of years old to our attempts to better understand the behavior of the massive Ross Ice Shelf under changing climatic conditions.

INTRO—SEQUENCE 3: HOW TO HANDLE TECHNICAL INNOVATIONS

[Intro videos: Part 3.1 and Part 3.2]

Look around you: you are most probably surrounded by an amazing number of material devices. Some of them appear very rudimentary and have been around for millennia — a hammer, a basket, a needle; others are so complex that you might have no idea on how nor why it works — the computer on which you work for this class, the microwave in which you heat your mug. Some are already so clearly dated and outdated that they begin to look like works of art — a Buick from the 1950s, an old coffee grinder with a handle just as your grand mother used it, a shot gun from the past century, a sickle from a farm long gone. Some are so costly that you are not allowed nor able to make them work while others look so puzzling in their form and function that you wonder for whom and for what they have been devised. Try to list every material item around you: you will be tired before having gone through one single room — and don't start with the kitchen or the garage!

Those material devices, or to use the term proposed by anthropologists, those "technical artifacts", enter into the quasi-totality of our daily action. Try to cook, to write, to build, to travel, try to garden or to sow without using any artifact whatsoever! Well, you would not go very far. And yet, it is difficult to pay full justice to the mass of work, of action, those artifacts do for us and with us. If you say: "But they are just tools", you don't treat what they do with enough generosity, since obviously without, for instance, an electric saw you would not have even begun to contemplate building a doll house for your little brothers; without a needle, your fingers will never have itched to cut and fashion a dress; and who will have the idea of blowing through a trumpet without a trumpet at hand? Without the help of a computer, how would you have even thought of taking a course with distant Frenchmen in Paris?! In other words, the device made you think of doing new things. So, technical artifacts are at once allowing action and proposing new goals.

Of course, such a complex action — or agency — is pretty difficult to detect when we deal with objects that are so well entrenched in your daily life that you don't even imagine that they might have not been there all along. You take your car without another thought because you want to go somewhere at will: for you, it's just a tool that simply fulfills your desire to move. How could you remember the time, less than a century ago, when the very desire to go far and quickly, in complete autonomy, was slowly made possible, only for wealthy people, by the development of cars against the development of public transportation, especially tramways? How could you? I am pretty sure you have already forgotten the time when you could not send instant messages to your loved ones through your mobile phone.

Don't feel bad about it: such a forgetting is the very function of technical artifacts: once they have been put into place, once they have invented goals for us, we entirely forget their presence. They simply shape silently the material infrastructure inside which we live.

And that is the big problem we have to tackle in this sequence: artifacts are not isolated bits of engineering brought each spring by the beaks of benevolent storks. They are accompanied by quite a number of other phenomena that we take for granted when we accept to use any of them. Technical artifacts have been devised by people according to plans which might differ from yours quite a lot. Since once in place they disappear from view, those hidden goals will last for very long without you being able to detect what they make you do surreptitiously. Their ability to quickly become silent and invisible makes them incredibly powerful forces in molding our daily work. To use a catch phrase from the field of science studies: "artifacts have politics".

The aim of this sequence is to develop enough interpretative skills to detect, to trace, and may be, one day, for you to influence, such politics. How are we going to do that? Just as we did in the former weeks: I am sure that in gathering material for your blog you have noticed many events that were not about a new piece of knowledge but about the *introduction* of new techniques. For instance, if there is a company in your neighborhood that tries to introduce the oil recovery technique known as "fracking", you will have detected lots of reactions against this technique. Since it is not part of the landscape yet, you can easily see the work necessary to *make* it part of the landscape. You might have noticed less dramatic cases as well: a coffee company, for another instance, is attempting to sell doses of your favorite beverage in minute capsules that seem to conservationists a complete waste of precious material. The more protestations there are, the easier it is for you to take this new process for a violent attempt to modify a tiny part of your behavior. When you read, to take a third example, about militants of free software fighting against the many dangers of proprietary programs, you understand that what seems to run smoothly on your screen might make you do all sorts of things you might not wish to do. All those cases have to be carefully recorded: they are the best entry into the politics of artifacts.

To become attentive to such politics, we are going to treat technical artifacts not as so many "objects" — pieces of material stuff but as "projects". We will add to them everything that allows them to work. You will quickly see that projects are much more lively animals than objects. For one thing, they have a history. They come and go. For another, they are full of people, inventors, financiers, lawyers, ethicists, government officials, politicians, consumers, each of them with his or her strategies, skills and life trajectory. Then, each project attempts at forming a system, that is, at making all the other artifacts around them serve their own goals. They never succeed, of course, but all those aborted systems create a highly complex ecology more entangled than a deep

jungle. Then you will discover that projects, even once they have become entire infrastructure, remain pretty fragile. They might break down; a strike may idle them; another project may render them obsolete; another legal framework may make them too costly. Even when they are said to "run automatically" they need quite a lot of work to keep them up. What you are going to discover is the "life of things" and "the career of objects".

With this sequence, every thing that seems solid will be set in motion; every thing that seems dead material will become alive; everything that seems part of the natural landscape will become a vast building site; everything that seems destiny, will become decision. You will recover a feel and a taste for a material world that has been made, so far, without you, and that, incredibly enough, is almost totally ignored by the field of humanities. But also totally misrepresented by what is called "technical hype". Projects are very, very far from the ideas of control, mastery, rationality, efficiency and progress often associated with "new" techniques. Innovations are fabulous to study but not because they are efficient, because they are so deeply humans. In this sequence, be ready to get your hands wet and dirty. You will have to be attentive to all sorts of little details. God is in the details, but so is the Devil.

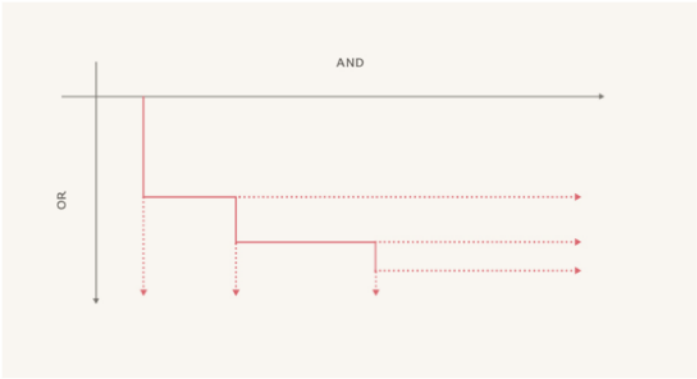
How to move from object to project

What makes technical objects invisible to us, most of the time, is that they are seen in three dimensions as many pieces of stuff. The fourth dimension, that of time, is always ignored. And yet, they have a history and often a complex one. The problem is to learn how to represent such a movement. The first thing is to treat techniques as projects, not as objects. Then, we need to learn how to list the many episodes that make up the life history of the project. Especially difficult is the fact that, for most of the period in a life of the project, there is no object at all, but only ideas, meetings, blueprints, papers, discussions and disputes. Being an object, for a technique, is only a moment. And when the project fails to deliver an object, there is nothing to see but ruins and carcasses.

Before saying more, and to give you a feel for what it means to follow a project, we have chosen a film that represents, through specifically drawn diagrams, the whole history of a British military plane that has been studied by two of the great sociologists of techniques, Michel Callon and John Law. Here is the TSR-2 Aircraft Project.

Follow the front line of a project

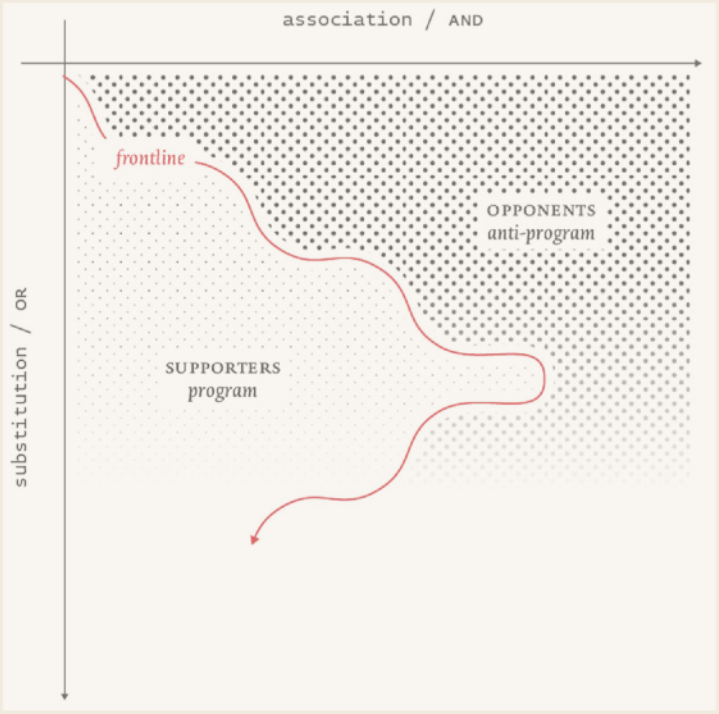
I realize it's hard to get something like the TSR-2 project across in prose. And it's precisely to convey that animated character of any technical object that I need to make my earlier diagram a bit more precise, to highlight both dimensions: left to right, which I call association; and top to bottom, which I call substitution. These dimensions can be further simplified by coding the first with the symbol "AND" and the second with the symbol "OR".



Don't look for any geometrical precision, that's just another, more orderly way of representing movement by detours (OR) and compositions (AND), so that we will have a thread to make our way through the labyrinth of technology. It will then be possible to say of any object that it is only a temporary stage (a horizontal line), extracted from the series of transformations that the initial project had to undergo in order to modify the range of its opponents and supporters. The only advantage to that way of presenting things is that it's easy to add, one beneath another, the successive versions of a single object as a function of events, as if you were writing down statements describing the project, being careful, for the sake of convention, to begin with the "pros" and then move on to the "cons".

The important point is to make it quite clear that any displacement along the composition or association (AND) dimension is offset, if you will, by a movement along the detour or substitution (OR) dimension. In other words, technological invention never proceeds in a

straight line; rather, it zigzags between a multitude of compromises. In my diagram, these continual maneuvers, which define invention, trace the front line between "friends" and "enemies," those who had to be held onto or fought against every time. That line must become our Ariadne's thread. (When I say "friends" and "enemies," I also mean support and obstacles, or more generally, programs and antiprograms, since, of course, not only human beings are at issue but also materials, machines, patents, and so on).



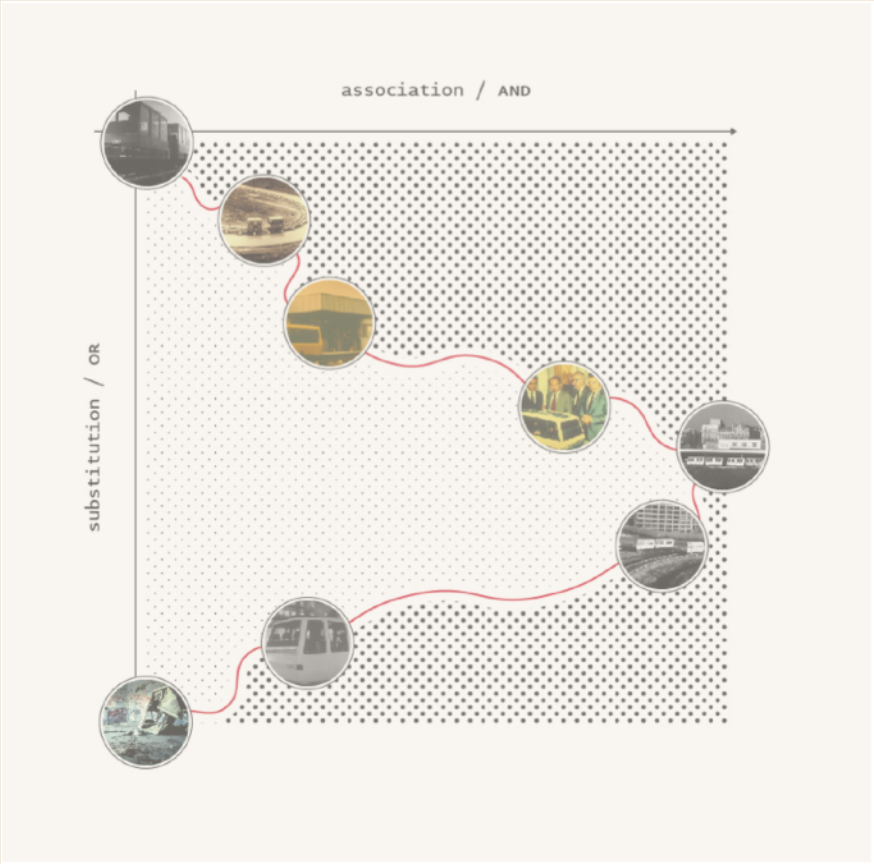
The great advantage of that simplified visualization is that it helps you to grasp technology as a project and not as an object. Or rather, the object exists, but only as a cross-section at instant **t.** The object is a freeze-frame in the film of the project.

It's a simple argument, but you risk forgetting it so long as you are still fascinated by the object all by itself, suspended, interrupted, effective. You would need to do for technology what Darwin taught us to do for the sequence of living beings. If you go to the Museum of Natural History and look at the horse series, you know you mustn't focus on any single one of the successive specimens, but that their true essence is, shall I say, found in the entire line, branching out from predecessors to successors. Now if you go to a museum of technology, to the Deutsches Museum in Munich, for example, and you see the long series of bicycles, you would have to do the same thing: not pause on one or another specimen but see them all in motion, coming from one model and heading toward another, as a function of need, cost, habit, fashion, builder, material, and so forth.

Aramis, or how to represent the life story of a project

In the following diagram, I have summarized (rather grossly) the life story of a project using the association/ substitution diagram I have presented above. This is the marvelous story of an automated transport system called Aramis, to which I have dedicated a whole book (one of the few that follows from beginning to end a technical project). I have illustrated the series of transformations the project undergoes by using little snippets taken from the book (*Aramis or the Love of Technology*. Trans. Porter, Catherine. Cambridge, Mass: Harvard University Press, 1996.). You will find a more complete photo essay here. It begins as a totally make shift set of two vehicles able to follow one another electronically without touching one another. That's the proof of concept phase. Then it becomes more and more elaborate until at moment 4, you see all sort of investors assembled around the scale model of a future transit system. The prototype is being built (phase 5 and 6) but then all the

investors, one after the other, begin to leave the project. No substitution (the OR vertical dimension) seems enough to insure the shift toward the left side of the association (the AND horizontal one). The project is indeed transformed, but what was a few years earlier a revolutionary transit system has become a wreck! The point is that there is no way to move toward existence without transformation but that each transformation may increase or decrease the number of entities allied with the project.



It's somewhat as if every technical object were to become a page in a flip book, whose pages you would learn how to flip very quickly, in order to take in only movement.

As one more example, and to have a *non*-evolutionist overview of a technical object's life, focus on the engine of the Formula One racing car in this video; given what has been said here and at other points of the course thus far, one wonders why the producers of the video describe the process as evolutionary.

INTRO—SEQUENCE 4: HOW TO DEAL WITH CONTROVERSIES
[Intro videos: Part 4.1, Part 4.2 and Part 4.3]

Now that, thanks to your blog, you have learned how to follow complex imbroglios of science, technology and public affairs, we are going to enter into a much more complicated question. You have surely noticed that on the many topics you have been following, be they in health, ecology, sociology, law, politics or economics, the experts who have been mobilized do not always agree among themselves. They seem to be engaged in what "could be called controversies", especially when we give this expression a very wide range of application so that the same term may cover every sort of dissent from minute disagreements between small groups of highly specialized scientists to public issues that mobilize laymen in the street.

On many topics, we find this state of affairs quite normal and there exist procedures to settle those disputes. This is clearly the case in legal matters: since lawyers represent various contradictory interests, we are not surprised that judges and juries have to make up their mind after cross-examination and pleading. This is clearly the case also for political disputes that are solved by votes, referendums or elections. But it is much more surprising to hear that, when dealing with scientific and technical matters, it is often difficult to assemble the advice that settles the case in such a final form. There are often huge disagreements on, for instance, the feasibility of a "smart" electrical network, the profitability of a pipeline, the efficacy of a cancer cure, the predictability of an ecological catastrophe, and so on and so forth. Your blogs are full of those disputes. Unfortunately, for settling such disagreements, there exists no procedure that would be as widely accepted and as thoroughly instrumented as those that exist to settle legal cases. And yet controversies have to be settled for the scientific and technical affairs just as well. We cannot proceed through any course of action in the midst of too many uncertainties. Cases have to be closed.

To delineate such a procedure, is the object of this fourth sequence, a more difficult and risky lesson than the others. We are going to have to learn how to *map controversies* from their beginnings all the way to their end and to recognize, at every step, why they are opened in the first place, how they develop, why they are sometimes closed too quickly or, on the contrary, needlessly reopened. To do so we are going to need to develop a lot of interpretative skills to educate ourselves in having the right taste or the right feel for dealing with the many controversies on which we are so often asked to take a stand. This is where the field of "scientific humanities" really deserves its name.

Let me first review with you three major problems that render such a mapping a difficult enterprise.

The first massive difficulty is that, with very few exceptions, we are rarely ourselves specialists of the detailed content of the case at hand. The likelihood that we ourselves have published any statement on the topic under discussion is nil, if by "publication" we mean what has been learned in sequence two: a scientific paper in a refereed journal that has been taken up and cited by later peers. And this is true of course if we are a layman in biological, chemical or engineering matters, but this is just as true for biologists, chemists and engineers for the controversies that are raging in the domains that are adjacent to theirs and for which, nonetheless, they need closure to get on with their own business. The fields are so specialized that certainties from one specialty do not easily spill over to the next one. Of course you may decide to become a specialist in the next domain by double checking the results of their papers but, for most topics, this would require a lifetime of learning and, if you don't succeed in becoming a peer of those you criticize, you would end up doing nothing more than needlessly meddling. So in all cases, we have to trust the experts without being able to go inside the details of their proofs.

But *whom* to trust? That's the tricky question. The great solution would be to say: "Trust the scientific community most relevant for the issue at hand". That would be ideal because we could discard all the statements of those who are not scientific - they just have "opinions" not "knowledge" about the issue - or we could discard all the statements which may be "scientific" but "irrelevant" for settling the question. But the problem is that this solution is just that: an ideal. In practice, it is very difficult to establish the limits of what is a "relevant scientific community". Most disputes, when we are drawn to them, begin by claims that this or that scientist is not "really" a scientist or that this type of expertise is not the "most relevant" to close the question. So the problem of whom to trust is not that easy to settle as you can see for yourselves by following the same disputes over several months through your blogs.

So we need another solution if we are to place our trust in this or that party to a controversy for which we will always remain a partial outsider but which needs to be closed first so that we may take action. Naturally, those of us inside the domain we sort of control or survey have a fairly good assessment of who is reliable and who is relevant or not. A good shoemaker will probably know who and where the good shoemakers are just as well as a molecular biologist will assess whom to ask for the most pertinent advice in case of trouble with her experiment. In both cases, this assessment is based on a variety of sensors and captors: the quality of the people, the reliability of the production, the feedback from consumers or colleagues, the length of the track records on which to judge the output, the awards received from such and such academies, and of course the direct testing of the results. Is it possible for *outsiders* to develop quickly at least some of those skills that *insiders* seem to have acquired through a long training? That is the question that the mapping of controversies is trying to answer by developing various tools which, taken together,

may act as a prosthesis for not being an insider and still being able to make up one's mind about whom to trust by detecting who is the less partisan party in the dispute.

The second equally massive difficulty is that most protagonists in the controversies will use the adjective "scientific" do describe a statement that is neither "political", nor "irrational". Again, that would be an ideal use of the adjective if it could be used uncontroversially. But unfortunately this is not the case. As you have learned in sequence one, delineating what is "scientific" and what is not scientific is the most difficult thing to do since the autonomy of science is possible precisely because of the number of external factors making such an autonomy possible. As we have seen earlier, stressing only the autonomy of science makes about as much sense as stating that a nuclear reactor is "autonomous": well, yes, it better be, but on the condition that a whole technical system be built around it to hold it tight.

But here we encounter a major problem because if I say "This is not a scientific statement, it's a political one", you will immediately conclude that it is not an accurate objective one, that it has been "distorted" by the biases and interests of those who uttered it. Is "scientific", in the common usage of the word, what has not been distorted by politics on the assumption that left to themselves, completely autonomous states of affairs go just as straight as an apple falling to the ground. And even if you have learned in the three latest sequences that this idea makes no sense, there seems to be no alternative. Either it is "scientific" or it is "rhetorical".

Well, the great advantage of bringing the "humanities" to bear on scientific practice is that in the field of humanities there are a lot of resources to study what is rhetorical because of the field's emphasis on the materiality of language and speech. And if you begin to be attentive to language, as you should be, it is not too difficult to ferret out an alternative to the "science" versus "rhetoric" way of thinking. It is simply that, most of the time, we designate as "scientific" not only a state of affairs coming straight from nature without any distortion, but also a certain *style* of writing papers, reports and documentation. A style where all indications of rhetoric seem to have been erased.

But those signs are there nonetheless, so that we can now differentiate not "science" from "rhetoric" but rather two types of rhetoric, one that erases as much as possible all traces that it is a textual account (it is just a clear and transparent window pane through which the world is seen) and another one that multiplies the tell tale signs that it is indeed a textual account (at the limit it could appear as poetry). So, in spite of the insistence on the difference between "demonstrating" something and "convincing" or "persuading'" someone of something, a difference that dates from the Greek and that is a powerful political way of closing the discussion, we had better learn to map out all the tools that are mobilized in opening or closing discussion. It does not mean of course that there are no incontrovertible facts, it only means that

incontrovertibility is the *final* state of a process that has to be followed from beginning to end.

The third major difficulty we have to tackle (I told you this is a tricky sequence!) is that the word controversy itself is controversial... As you will see in considering this hilarious Doonesbury strip, the word is also used to create the impression that a case is still open even when it has been closed tight by experts who are in full agreement about it! The idea is to maintain two sides facing one another even when there are no longer two. This is for instance the case, well known in the United States, where people talk of the controversy over evolution as if there existed another equally scientific camp made up of creationists or lately, "intelligent design" specialists. More politically important, is the idea, forcefully developed by powerful interests, that there is a "climate controversy" as if there were two scientific camps, one made of experts claiming that human action is responsible for "global warming" and another who claims that humans are not responsible for "climate change".

Even though those spurious controversies are extremely popular (especially among the media who love to have two parties on a TV stage as if journalists were judges in the law court) what you are going to learn in this sequence might dispose of them: just consider who are the scientists to trust after you have mapped the controversy. Using the definition proposed in sequence one and two you will have no difficulty weighing the respective sides: who are those who publish peer-reviewed papers? Once you do that, you might see that the two "sides" are not made up of the same type of "experts" at all and that it would be a mistake to talk as if there were two sides. Seeing this does not mean the dispute will stop; it means that you will learn to detect who is more partisan than whom. And that is the best goal that, as an outsider, you may achieve. We will see in the last sequence, what this could mean for the definition of the citizen of a new democracy. But first we have to provide such a citizen with some equipment in order to map out the issues at hand without being intimidated by the many contradictory claims of each party as being "more scientific than thou".

Here learning how to interpret many disjointed evidence is the skill that trumps all the others.

How to explore the richness of controversies (by Tommaso Venturini)

To explore the richness of controversies without getting lost in their complexity, it is useful to draw maps of them. Not only geographical maps, but more generally visualizations allowing to deploy the alliances and oppositions between actors and ideas active in a dispute. To be sure, it is impossible to reduce the intricacy of a sociotechnical controversy in a single map. It is however possible to capture the richness of a controversy through a series of maps. An atlas is the description of an exploration. As the mythological figure from which it borrows its name, it bears a reality providing it with meaning. An atlas is the result of two distinct actions: going in -the action of observing- by which we try to get in contact with a subject and going out -the action of telling- by which we reconnect and compose the elements we observed. In two articles, we described a path through the complexity of controversies (Venturini, 2009) and a series of controversy maps (Venturini, 2010). Here we shall put them together to describe the structure of a controversy atlas. Other concatenations are certainly possible. What is important is to break down the richness of a controversy and then rebuild it through a chain of subsequent representations.

There are countless ways for sociotechnical controversies to emerge. Sometimes, controversies are triggered by the disagreement between the scientists working on them. Sometimes, they derive from the large-scale commercialization of a previously experimental technology. Sometimes, as in the case of the fracking, controversies are launched by actors (also called whistleblowers) who, by-passing the official scientific communication channels, succeed in mobilizing the public opinion around a technological issue. For the fracking technology such role has been played by Gasland an American documentary written and directed by Josh Fox and published in 2010.

Here we provide an example taken from the work done by one of our best groups of students at the University of Politecnico of Milano (Density Design Lab) on the hydraulic fracturing/fracking controversy. You can read the full report of the students here:

Inventing the right digital tools

The whole history of democratic institution shows the way: by taking the opportunity provided by rather unrelated technical innovations to bear on the citizens' equipment. What is the most promising instrument at hand to assemble around an issue? Clearly these are the new digital techniques even though our project feeds also on many other non-digital resources. It is not the web as such that interests us, but rather the digitalisation of many apparently unrelated sets of information and practices that could not before be brought together in the same optically coherent space.

Hence the necessity for the students to learn the practical tools to represent in a new way scientific and technical controversies, so as to equip the potential public and turn it into a real representative arena. This is why we need to have the issues at hand represented anew. Even though it is a pedagogical exercise, as we will see in sequence 7, it is not limited to it. It aims at creating an arena where the issues are assembled and the judgments passed are made more legitimate.

If the printing press has been so important for the invention of critical spirit and, in the end, of democracy, it is not because of the movable characters in themselves, but rather because the printed book allowed to literally draw together completely foreign domains of practices. This is especially true for scientific books when for the first time reliable images and correctable texts were simultaneously visible on the same page. The cognitive abilities of readers all over the world were modified. The same thing can be said of the visual space offered when utterly different sources of information, because they are all digitalized (even though the data sets are far from being standardized –see below), can be inspected by the same set of users. We expect a deep transformation in the ability of the public to represent the issues at hand from this new acceleration in the compatibility of hitherto unrelated data sets. Printed books did not aim at fostering democracy, the critique of authority was an unexpected (and often unwanted) consequence; the same thing is true of digitalization: nothing in this technical domain was made "for democracy". And yet, it can be translated, we believe, in a powerful tool to promote technical and scientific democracy finally overcoming problems identified long ago.

The main reason is already visible in many various endeavours to promote a new form of representative collective: because they are similarly digital the same tools can be applied simultaneously on scientific data sets as well as on non-scientific sources of information. Whereas in earlier times you had to have one set of competences for knowledge (access to scientific libraries, photocopy machines) and another set of competences for opinions (reading newspapers, doing surveys), it is now possible to have in the same optically coherent space (in most case, a computer screen), data sets coming from the inner sanctum of scientific production and from the wildest rumours on the blogosphere. The rarefied domain of the logos and the down to earth domain of the blogs have been made comparable. This is of immense relevance for following issues where, precisely, facts and opinions are hopelessly mixed up.

This is why mapping controversies aims at building a site to seize all the opportunities allowed by digitalization that render compatible –and thus simultaneously visible and representative- hitherto foreign, costly, rare and incompatible –or simply inaccessible- sources of information on a given issue. Not to use such new techniques to promote representative democracy on issues of science would be as silly as if democrats, in the 19th century had refused to use the press to promote the artificial construction of opinion.

Living happily in a controversial world (by Tommaso Venturini)

Never before today, has collective life been so difficult to compose. Not because social existence has ever been easy, but because we have never been so many to share our lives and depend on each other. The extensions of technical infrastructures, the interlock of markets, the standardization of communication channels, everything seems to bring us closer and bound us tighter. It is not that all barriers have fallen, of course. It is that barriers resemble less a dam and more a pump restlessly displacing resources to maintain the differential. And it is not just the human beings: the development of sciences and technologies has put us in contact with the smallest amino acids in our blood and the highest layers of the atmosphere, the krill floating in the Antarctic sea and oil trapped in the deepest geological strata. Little we can buy, vote or do, without interfering with economies and ecologies on the other side of the planet. The consequences of our actions have filled the earth (think of the growing problem of garbage landfill), the seas (with huge plastic garbage patches floating in every ocean) and the atmosphere (producing a direct effect on the climate of our planet). We reached out for the space just to turn and realize that we are stuck on a green-blue ping-pong ball. Billions of us: women and men, animals and objects, technical and natural elements. No wonder our condominium meetings are growing tenser.

Current proliferation of controversies

No wonder, sociotechnical controversies have multiplied and progressively occupied the center of our collective life. The recent proliferation of controversy is both a good and a bad news. It is a good news, because it derives in part from a growing demand of transparency. Sciences and technologies have become so pervasive and influential that more and more people demand their dynamics to be publicly discussed. In the dawn of the anthropocene, while technoscientific forces take control of the evolution of our planet, the debate on science and technology cannot but become more visible. Too many times the purity of science and the myth of its infallible consensus have been used to exclude non-experts from the discussion: "no need for public discussion, Science will decide". Confining quarrels within the walls of scientific laboratories, of course, has never dampened controversies, but it did make them less visible. The increasing visibility of controversies is therefore a consequence of a long-awaited and legitimated demand for democratization of techno-scientific debates. And it is therefore good news.

At the same time, the multiplication of controversies is bad news because it partly derives from the increasing ability of lobbies to deliberately feed scientific disputes in order to stall political action. First employed by tobacco industries to undermine the smoking-cancer connection, this sceptical strategy is now applied to issues so distant as climate change, acid rains and ozone depletion (often by the same sceptics organizations). The proliferation of controversies derives from these two movements: the failure of the long-established strategy of silencing public debate through the supposed infallibility of science and the raise of the new strategy of silencing public debate by drowning it in a talk-show's cacophony. The (evil) genius of this strategy is to highlight the disagreements among the experts amplifying the complexity of science to the point of making it completely opaque: "discuss as long as you want, if Science can't decide no one will". The strategy is opposite, but the result is the same: the exclusion of non-experts from the technoscientific debate.

The recent proliferation of controversies derives from these two parallel movements: the failure of the long-established strategy of silencing public debate through the supposed harmony of science, and the rise of the new strategy of silencing public debate by drowning it in talk-shows' cacophony.

We will call positivism the first strategy and relativism the second. Controversy mapping is opposed to both and its goal is to teach students (and future engaged citizens) to deal with sociotechnical controversies. This unit will teach you not to be afraid to open the Pandora's box of scientific disputes, to follow their actors and deploy their imbroglios. But it will also teach you how to work to close controversies, how to form your opinion on them and decide which actors require your surveillance and which deserve your support.

SEQUENCE 5: FEEDBACK ON SELECTED BLOGS DONE BY MOOC STUDENTS

To start—three controversies considered jointly: Questions about translation and composition; Can fish feel pain?; Following a statement about electronic waste

Canadian government science cutbacks

Awaiting decision on genetically-modified insect field trial

The global AIDS response can help in fighting hepatitis

Who gets to count as an expert?

Want a smarter city? Then indulge in time travel

Private natural catastrophes

The war against worms

INTRO—SEQUENCE 6: HOW TO UNDERSTAND THE SHIFTING NATURE OF THE NATURAL WORLD?
[Intro videos: Part 6.1 and Part 6.2]

Now that you have become conversant in scientific humanities, you might be ready to take a larger view of the subject matter and consider a wider span of history, taking humanity as a whole in its relation with science and technology.

You must have realized by now that if you attempt to describe in your logbook all the instances of a link between science, technology and the rest of culture, society or politics, you end up registering almost all the news! Extremely rare are the events that do not depend on the impact of a new piece of technology or which do not appeal to a highly specialized domain of expertise. And this is true for natural as well as for social sciences — and also, as you have now learned to recognize, it is true for all the more obscure disciplines like management, accounting, and logistics, that is, for the myriads of specialists that have rendered themselves necessary for the achievement of any course of action.

And that's the problem we have to tackle now in sequence 6: how is it that science, technology and society have become co-extensive, so that it has become impossible to study one without studying the others? If we grasp this situation, you will be quite surprised to notice that, in spite of this by now obvious phenomenon, common sense tells us that we should keep "science" and "culture" as distinct as possible from one another! How puzzling it is to entertain simultaneously two completely different views of the same world we inhabit. This duality is at the heart of scientific humanities. We will have to tackle it.

To fathom such a contradiction, let's begin with a little thought experiment. Try to take away, one by one, the artifacts which you have to "go through" in order to achieve any action. Start by shutting down the computer on which you watch this video… Careful, your connection with me will be cut off. Then, try to make yourself a mug of coffee. No, no, don't use the coffee machine: it is gone! Now you have to go fetch your coffee beans by yourself and find a way to grind them with a stone. But your car is gone too, and so is public transportation. Sorry to say but you now have to walk to fetch your coffee! If coffee does not grow where you live, say bye-bye to this beverage: you are back to the situation of Europeans before the 17 th century. They had no coffee to stimulate their neurons.

If you want to render this thought experiment more dramatic, read a science-fiction novel like David Brin's The Postman or watch the film with Kevin Costner. You will quickly realize how easy it is to connect a state of technology with a state of society! To the point where one can say that describing a set of artifacts or describing a set of social relations amounts to describing the same thing twice but in a different

order. Granted the existence of "a letter with a stamp", a whole civilization is made alive; or, conversely, for a postman to be given the authority to carry the letter to someone else far away, a whole civilization must be firmly in place.

Now, try to pursue the same thought experiment, not, this time, in the realm of artifacts, but in the realm of expert knowledge. Imagine that historians have disappeared entirely from the surface of the Earth: what would you know of what tradition you inherit? Get rid of cartographers and geographers, and where would you situate your country or your city in relation with all the others? Without archeologists and paleontologists, you would be reduced to a tiny span of history, to a moment isolated in a complete vacuum. Take economists, statisticians and accountants away: gone would be the very idea of an economy to which you belong. You depend on all of them. Without them you end up being just an individual, an atom, a vanishing point.

And this is just the beginning: take away natural history, how would you know of all the species making up the biosphere, and if you find yourself in charge of a hospital deserted by physicians, nurses, biologists and laboratory technicians, what would you make of diseases and epidemics? You will be unable to do anything to save any patient. Biology, physics, and chemistry depend on the institutions of science just as much as the knowledge of ancient Greek or that of Shakespeare Early Modern English depends on the continuing existence of scholars able to inherit the documents of the past and decipher their cryptic readings. Without those domains of expertise, you would be reduced to a know-nothing, a naked moron lost in space and time. You depend so much on the production of expert knowledge, that describing the society you live in or the knowledge infrastructure you depend on, once again, amounts to describing the same phenomenon twice.

Once you have engaged in such a thought experiment, you might want to take a new look at the longer history of humanity in its connection with the extension of technology and the expansion of its knowledge infrastructure. It is not so difficult to do if you consider the notion of the "footprint" that humanity leaves behind in its movement throughout history. Anthropologists, paleontologists, ecologists, and archeologists have reconstructed many different ways for human societies to mobilize elements of the world around them. Although there is no evolution from one stage to the next — as if older societies were more "primitive" or "simpler" than the present ones —, there exists nonetheless a trend that is easily discernible: the growing extent of the footprint of human action throughout the "natural" world.

At the time of Ötzi, the 5000 year-old Ice Age man found preserved in an Alpine glacier along with his clothing and equipment, his footprint and that of his society were tiny compared to the one you leave around yourself today. And yet, he was already transforming his environment to a considerable extent and relied on a subtle

knowledge that made him just as dependent on expertise as you do now. However, Ötzi was most probably able to fabricate by himself all the equipment he carried on his back. We are not. While only archeologists may find the tiny traces his civilization left in the valleys of the Alps, the traces we leave on the Earth are visible everywhere to the naked eye. So, what is different is the *scale* at which this transformation of the natural world occurs and the *extent* of our reliance on a vast knowledge infrastructure, each component of which we do not master by ourselves but only by trusting other specialists.

Such a view of human history might have seemed far-fetched at the time of Karl Marx or provocative at the beginning of the field of science studies, but it has become fairly obvious with the invention, by geologists and climatologists, of the notion of the Anthropocene. You certainly remember, because you have learned it at school, that each moment of the history of the Earth has been given a name: "Permian", "Cretaceous", "Pleistocene" and so on. Those names have been chosen so as to highlight the most important force at work in shaping the face of our planet in that period. Well, it happens that some geologists are arguing that the most important force at work is now humanity taken as a whole. Not you and me individually, but all of us in association with our industry, agriculture, transportation, military infrastructure and communication systems. For geologists, the scale of human intervention in the workings of the Earth system has become as big — if not bigger — than that of volcanoes, rivers, vegetation, oceans, or even plate tectonics. What a change from the time of Ötzi!

The point of interest for us is that, thanks to the dramatic rise of humanity's impact, it becomes obvious that describing human action or describing science and technology amounts to the same thing twice.

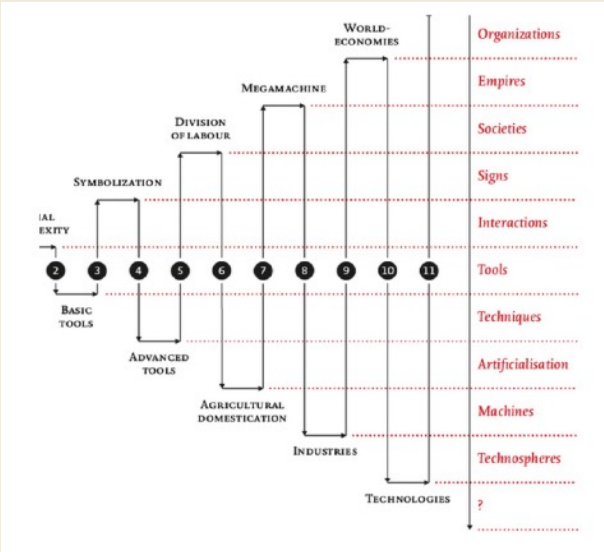
And that is the main insight of scientific humanities. If you wish to study the nitrogen cycle on Earth, you will have to take into account the factories in which nitrogen is being fabricated through a process invented by the Nobel Laureate Fritz Haber (1868-1934) and many of his chemistry colleagues at the beginning of the 20th century. You begin with a natural phenomenon and you are led to a highly historical and social event: The German industrial system. But you can tell the story in reverse order: start with Haber and you will be led to an Earth-wide mechanism. Or to take what has become the most canonical example, if you wish to understand the Earth's climate, you will have to factor in the amount of CO2 generated since the industrial revolution by modern ways of life. A "natural process" or a "socio political system"those are the two faces of the same coin. That's what the notion of the Anthropocene as a period of history — but we should really say a period of *geo history* — summarizes in one single convenient concept.

Which leaves us with a big problem: if this is true, why is it so difficult, for common sense, to relate science with the rest of culture? To the point where the main injunction is that the two should remain as distinct as possible so that the authority and autonomy of science, as well as the autonomy and efficacy of technology will not be threatened by the vagaries of politics, the illusions of ideology or the dreams of poetry. Everything happens as if there existed two opposing forms of common sense. That's where scientific humanities encounter politics head on.

History of humans, history of things

To finish things off, I need to add one last feature (I'm obviously anticipating what will come later), which is that we have arrived at a new stage. We must now take into account not only the multiplication of the technological detours, not only the prolongation of each one, the necessity of going through increasingly esoteric and increasingly better equipped sciences. In addition, it turns out that many of these sciences give rise to public controversies (that is the full importance of your example of the unexpected linkage between democracy and an incineration plant). The big event in Copenhagen in 2009, a global climate conference, is something Ötzi would have been unable to imagine—but then, so too would Cyrus Smith. Like the Gauls (or so they say), Ötzi might have been afraid that "the sky was falling down on him"; but for Cyrus Smith, that was a figure of speech, which he would have mocked as proof of foolish superstition. No one would make fun of it today, since it is no longer just a manner of speaking: the sky may very well fall down upon our heads.

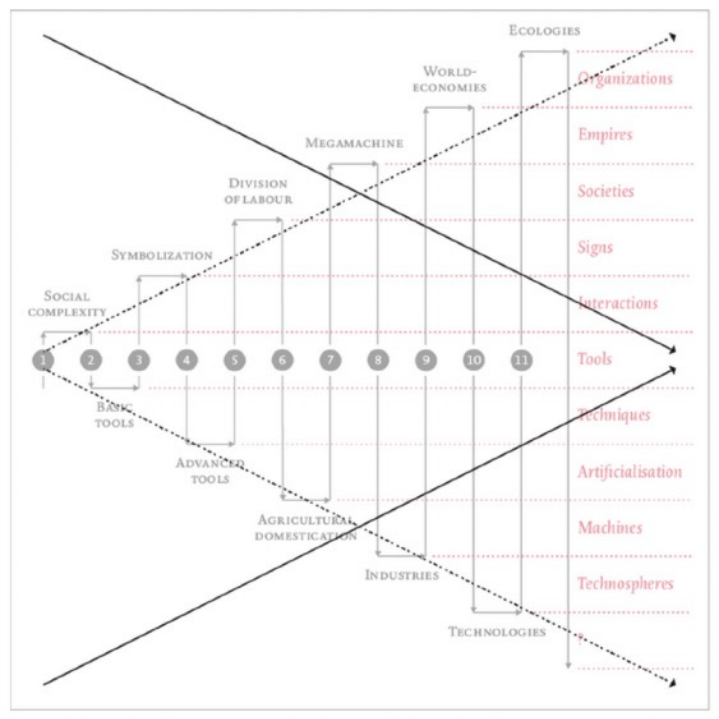
You see where I want to go with my students: the farther you advance in time, the less possible it is to distinguish human action from the use of technology, the recourse to science, and the invasion of politics. My favorite slogan is therefore, "To materialize is to socialize; to socialize is to materialize." I begin with baboons, who leave barely a visible trace on the territory, which they exploit with remarkable ecological skill, and I end with the soon-to-be nine billion humans who, for each of their activities, exploit increasingly large quantities of increasingly remote and composite materials. That activity even defines a new age, the Anthropocene (amusingly, it was a geologist who invented that expression, to make it congruent with the other eras in the earth's history), in which humanity is one of the factors capable of influencing the entire planet. It has reached the point that political assemblies, or rather, scientifico-political assemblies, must be invented to evaluate the risks and come up with solutions of the same magnitude as the problems. What a momentous event, when you consider it in such an offhand manner (yes, I know, very offhand), and when you take in the whole history of humanity's entanglements and composite materials!



I don't even hesitate to offer students a general diagram : the history of the world in a single page, in the form of a tapestry with woof and warp! The woof is provided by the new skills invented at each stage (I trace eleven landmark stages, whose exact names are unimportant) and which continue down to us (see the list on the right, which recapitulates them). The warp is traced by an even longer and more complex zigzag, mobilizing more humans each time (top row) thanks to the mobilization at each stage of the most intimate properties of a larger number of materials and organisms (bottom row).

The important thing is to grasp the scale (rendered inaccurately), which increases continually until the last stage, our own, which mobilizes the whole earth in the same stupefying maelstrom. And you'll notice the question mark at the end, which represents the present situation, for which we do not yet have a name: Will we ever be able to construct political institutions to comprehend, absorb, contain, and protect ecologies?

If I allow myself these exaggerations, these simplifications, and these shortcuts (which you'll no doubt find monstrous), it's because I want to arrive at my second question, the one about the meaning or philosophy to be given to that history. If these large-scale tendencies are accurate (and I believe that, with more time and data, I could convince you that they are), how is it that we still speak of technology and science as being realms distinct and separate from the rest of history? Moreover, how is it that all sorts of clever people tell you that, the farther you advance in time, the more distinct science becomes from history and politics? And on top of all that, how can they forcefully declare that science must be increasingly separate, so as to preserve the "autonomy" of fields of knowledge from the deleterious influence of politics?



It's as if two radically opposed interpretations could be given of the narrative I have just provided. The first assumes, at every stage, a radical break from the past, a break by which the subjective and the objective, the political and the scientific, humans and nonhumans, become increasingly distinct from one another—what I call the emancipation and modernization narrative (I'll tell you why later). Then there's a second interpretation, which assumes the reverse, a greater and greater, more and more intimate entanglement, at an ever-greater scale, via longer and longer detours between technology, science, and politics, more difficult to sort out each time. I call that second view the attachment and ecologization narrative. To revise my previous diagram (now grayed-out), it is as if it can be read either by following the dotted arrows, which move farther and farther away from each other or, on the contrary, by following the two solid arrows, which come closer and closer to each other. In one case, subjects constantly move away from objects; in the other, they move nearer together! It is not surprising that we have some trouble interpreting our own time.

In the first narrative, history involves increasing emancipation; in the second, it entails a multiplication of attachments and entanglements. The past too changes, depending on whether you follow one narrative or the other. So does the present, since we are not heir to the same events in each case. And, as a consequence, the future will be very different, depending on whether we are continuing the adventure of modernization or are setting to work to absorb all the attachments for which we have gradually become responsible. It is difficult to reconcile the two histories, though the phenomena they cover are exactly the same: namely, that vast history of connections between humans and things, of which I gave you an overly offhand view. As you may have already noticed, it is not possible to agree about the history of science and technology, and yet, all of our life in common depends on that impossible agreement.

You surely suspect the solution I'm going to propose, since it is similar to the one I offered in the first class: the two narratives are both true at the same time. It is therefore this new contradiction that must be taken as an object of study; and we must refrain from making it a resource and from cutting the Gordian knot too quickly. That, it seems to me, explains your initial anxiety: we all share it. But unfortunately, before we can grasp the sense of that contradiction, I must deal with slightly more complicated things. We learned that from Plutarch: as soon as we speak of science, we must protect our left flank and our right, while preparing to follow the paths of translation as well as the operations by which a "supernatural" knowledge will turn out to be disconnected from the contemptible world of practice.

Forgive me for covering too much ground in this summary and for rushing through so fast, which will tire you as much as it did my students. If there was one thing they did not expect, it was to have to endure a course in technology, followed by a course in the philosophy of history.

Otzi wears his whole technical system on his back

I ask my students, after I've shown the films, to take a look at themselves, there in the lecture hall, and to subtract in their minds, one by one, all the objects they must go through to enter into relationships with one another, until they are reduced to exactly the same level of technological nakedness as the baboons in the film. Obviously, I remind them that every time they have to "go through" something, that amounts to describing or tracing an operation of translation that obliges them to rely on a specialized knowledge, a technology —new or old—and sometimes on a more developed science. I therefore oblige them to deprive themselves bit by bit of computers, notebooks, and cell phones, then to work without a table, without a chair, without a wall. To remain decent, I stop the thought experiment at that point. They all find themselves dispersed in nature as "naked apes." They have of course preserved all their social skills—a sociability whose effects Shirley and many others have demonstrated—but they are completely unarmed or, in any case, unequipped, untooled: inermi, in the expression of André Leroi-Gouhan (1911–1986), founder in France of techno-logy (in the etymological sense of a science of technē). And if I ask them how they're now going to feed themselves, they are completely stupefied and baffled. Everything that used to come to them, they must now go out and get, and sometimes a long way out. I then take the liberty of criticizing their other instructors (my colleagues!), explaining that disciplines that fail to take technological detours into account may be interesting, but they are about baboons, not humans. Without technology, the humanities are only babooneries.

I then move on to Ötzi. Ötzi is the iceman from the Bronze Age five thousand years ago, who was found intact in 1991, on a col in the Alps between Austria and Italy. All his equipment was preserved by the cold: his weapons, his shoes, his small sack of materials for making fire, his first-aid kit, his food. Thanks to the perfect mummification of his body, we know what he ate, how developed his muscles were, how many wounds he had received—and we also know that he may have been murdered by an arrow to the back. What a find for archaeologists, who were quite familiar with the civilization of that time through stone, bone, and bronze tools, through skeletons and tombs, but who had never discovered a complete body, dressed, equipped with all its instruments, from the most luxurious, such as a splendid bronze ax, to the slightest, such as the antibiotic mushrooms or the fine stitching on his carefully lined hide boots. Why Ötzi? Because he provides a transition for students between the intensely social but technologically impoverished life of baboons and the contemporary age. Yes, I know, I'm going at it with a pickax, but let me be clear: I don't have much time and I need to get them to take in all of material history at once.

With Ötzi, I ask students to repeat the thought experiment involving the baboons, but this time I invite them to imagine what part of the equipment around them they would be capable of producing themselves, with their own knowledge and their own set of tools. Then they all look at one another and search for what they could really put together, relying only on themselves. Their computer? Hopeless. Their cell phone? No less hopeless. Their Bic pen? Their Clairefontaine notebook? Their backpack? The zipper on their jacket? Their socks, their shoes? No, not a chance. Sometimes I see a few hands go up and someone timidly points to a hand-knitted sweater, a piece of novelty jewelry, a stylish haircut. Very

few things on balance. That's the big difference that jumps out when we compare ourselves to Ötzi: we have the same bodies, the same brains, the same aptitude for language, and it is just as impossible for us as it was for him to survive without making use of the sophisticated technologies around us, which hold us in a sort of artificial protective bubble. But it seems that Ötzi could reproduce every piece of his equipment on his own, with the possible exception of his bronze ax, and that, as he traveled, he carried on his back and inside his head the entire technological apparatus of his people and his time. Who among us would be capable of that? If, by some horrible tragedy, a people knowing nothing about this world, but eager to reproduce it, had only me as an informer, with my ignorance and lacunae, what could I help them to re-create? Not even a toaster!

What, then, is the major difference between Ötzi's technical skill and our own? Well, of course, the prodigious extension of what I have called "detours and compositions." Each of our gestures is articulated by a much larger number of detours that oblige us to make use of ever more remote technologies, which themselves depend on increasingly specialized knowledge. The labyrinth gets longer, more complicated, darker. Back in the nineteenth century, Jules Verne could still imagine that Cyrus Smith, the ingenious "Robinson Crusoe" of his Mysterious Island, was capable of having his companions in misfortune reproduce, solely with the ingenuity of his accumulated skills, without a manual or a book, the entire industrial revolution—even the railroad lines!—without having preserved anything from the shipwreck but a wet match.

A trend of History

I claim therefore (I know I'll shock historians, who have a holy terror of any "law of history") that, from the baboons to Ötzi and Cyrus Smith to us, there is a trend, a general movement, that with each step increases the number and also the length of the detours. Let me summarize that trend for you in a few strokes, so that you'll see what I want to get at.

In the first place, at every stage (if there really are distinct stages, I'm not so sure), there is an invention that remains barely modified over the course of history: after all, our basic sociability is still that of the social primates, and we continue to use a hammer the way Ötzi must have done, just as we still raise livestock and grow seeds. There is thus an accumulation, a preservation, and a recomposition of all the skills that appeared in succession throughout history—no innovation has really been capable of abolishing completely the previous ones.

Then there is a lengthening of the detours, which it would probably not be impossible to quantify: the manufacture of Ötzi's bow (unfinished in fact), of his chamois leather quiver, and of his fifteen arrows requires a few dozen elements (from the birch wood tar to the green woodpecker feathers), extracted over several seasons within a range of a few kilometers; by contrast, my computer entails so many components, manufactured by so many companies, distributed among so many different countries and depending on commercial agreements and patents so dispersed, that no source allows us to indicate clearly how many materials, engineers, and workers it truly requires. We seem to have completely lost the trail of the translations and detours.

A third trait—and this is truly significant— is the ever greater extension of the nature of beings mobilized by that composite action. Ötzi's life depended on a large number of trees, bushes, fungi, other plants, and animals (several hundred have been counted). But as for us, we descend into the depths of the earth to extract coal and oil; in a plant, we sort out not just one seed from another, but the genes within each seed. It is as if we were getting more and more intimately involved in the components of matter, down to the molecules in biology, the atoms in chemistry, the particles in physics. That's the important point: contrary to the commonplace notion that, the more "advanced" science and technology become, the more we "lose direct contact with things," our relationship to things is actually much more intimate than Ötzi's was. And it is lucky for us that we have lost "direct" contact: we would still be in the Stone Age. Just because it does us a world of good to find ourselves with a hammer, a pick, or a knitting needle, doing something directly with our ten fingers, that does not prove that our relationships, taken collectively, are more remote. I very much agree that, subjectively, each of us individually has exactly the opposite impression; nevertheless, the Atomic Age, the age of DNA, presupposes closer bonds with things than did the Stone Age.

I believe that this key novelty differentiates our age from that of Jules Verne, however close it may be to us: each of these technological detours is now lengthened by a new detour within the detour, shall I say, which this time leads to scientific laboratories or to analysis and control laboratories (I explain all that in a different class). In other words, not only is every action composed by a technology, but that technology is in its turn accelerated, complicated, implicated, dependent on a newly created science. As we see in our journals, there is no agriculture today that does not go through a genetics laboratory, or at least through a seed selector; no city official's action that is not influenced by the report of a sociologist or an urban planner; no young mother's gesture that is not influenced by a manual on early childhood development or by the opinion of a psychologist; no lover's quarrel that can do without Freud.

INTRO—SEQUENCE 7: HOW TO BECOME A CITIZEN IN THE PUBLIC LIFE OF SCIENCE AND TECHNOLOGY?
[Intro videos: Part 7.1 and Part 7.2]

As you are now reaching the end of this class, you may be aware that you have more problems on your plate than you have solutions for them! Sorry to have somewhat disappointed you. But I warned you in advance: if you wanted solutions, you should not have taken this course.

What you might have learned along the way, however, is that the ideal solution to all the problems of science and society is just that: an ideal of no practical consequence. It would be nice to still insist on the radical distinction between the domain of Science and the domain of Politics; between the convincing conclusions of objective demonstrations and the uncertain connections of subjective rhetoric. It would be nice because, then, we could dream that ignorance and unreason will finally disappear from the face of the planet. We would just have to wait a little bit more for modernization to be completed. In the end, the power of demonstrations will defeat the vagaries of rhetoric and all human passions.

But as we saw in the last three classes, modernization has had exactly the opposite result: it has multiplied the controversies about what to do with technologies and what to expect from expert knowledge. To the point that we are now faced with two entirely different narratives of the recent human past: one is the Great Story of the Modernizing Frontier marching on; the other of more and more complicated imbroglios of humans with things. In one narrative, we expect more and more Emancipation from material constraints; in the other, many, many more Attachments with material constraints. Whereas we were expecting the glowing light of Modernization to illuminate the whole planet, the planet comes back but in the totally unexpected role of the Anthropocene. (see sequence 6)

Humans and things are always so enmeshed into one another, that it might be more prudent to abandon the ideal solution entirely. We have argued that, in order to handle the many controversial situations that arise from the extension of science and technology in all of our daily encounters, it might be more efficient to develop instead what we have called a set of *interpretative skills*.

It is traditional, I know, to oppose the *demonstrative* power of logical reasoning with the much weaker progress of *interpretation*. To the point that a division has often been made between the disciplines that depend on demonstration — mathematics above all — and those that depend on interpretation — history, law, literature, and, more generally, the humanities. But as soon as you have to find your way into a controversy, you realize that the demonstrations are only part of an overall puzzle, which is to 24 be completed by using educated guesses and common sense. To use a simple metaphor: we are not dealing with a solid continuous land with only a few scattered

patches of ignorance that will soon be cleared up up, but with an archipelago of more or less solid demonstrations spread out into a vast sea of ignorance. And to travel from one island to the next, we need navigation skills. Well, that's what we call *scientific humanities*. A fragile skiff yes, but without it, we would be stuck on one single tiny island of certainty without any vehicle to move on towards others!

The reason why we find it important to develop those interpretative skills, this alternative common sense, is because, whoever we are, at some point we will be summoned, willingly or unwillingly, to become citizens in a polity where we will have to take a stand on issues dealing with science and technology.

Take for instance the case of a first year councilman in Hawaii who is to vote on a motion banning Genetically Modified Organism. In days past it would have been settled faster by appointing a committee of scientists and they would have written a report on which the council would have voted. (Actually, in days of old, there might have been no discussion whatsoever: some state agency would have taken care of the problem without passing through any public debate.) But in this case, the poor councilman finds himself bombarded by letters from his constituencies threatening to recall him him if he votes "no". Appealing to expert witnesses does not help too much either, since even when they have impeccable credentials their positions might be tainted by corporate money. And when he gets to hear scientists from an independent university, the other party points out that the university has been favored by gifts from big corporations. The more he tries to make up his mind, the more controversial it becomes!

He soon realizes that the issue mobilizes a much wider set of arguments than those originating in Hawaii: cancerous rats from a Paris laboratory, Indian farmers committing suicide, big corporations in the Middle West, plus a bewildering range of knowledge new to him about pollens, cross-fertilization, patents, cultivars and papayas. And the councilman quickly realizes that making sense of the political spectrum is just as touchy as making sense of the pollination of plants.

Well, he finds himself thrown into exactly the sort of landscape that we have been exploring all along in this course.

Suppose now that, after you have become conversant in scientific humanities, the councilman asks for your help in mapping out this landscape and in advising him to take a stand. What would you do? This is the problem we have to tackle in this last sequence: how to equip citizens to make up their minds around issues that do not fit in the usual range of what counts as traditionally political? If you have a well-rehearsed set of positions for or against abortion or the minimum wage, chances are you don't have such a settled opinion on genetically modified papayas!

The first problem is of course to convince experts that citizens should have any say in the debate. Even if it is obvious in questions of agriculture and health that concern everybody, it is not always easy to define in what capacity the public should

intervene. For instance, if you are a patient suffering from a rare disease, do you have a say on your illness or are you accepted as having a voice only to complain about your suffering or to support the researchers? If you are a fisherman in South Africa, are you accepted in the debate as having "knowledge" about fish and fishing, or are you accepted there just to learn the facts of the matter or to complain about the esoteric calculations of fishery science?

The second problem is to avoid *meddling* in issues that are often so technically complex that it is impossible to tackle them by a thumbs up or thumbs down as you would do on Facebook. And yet, you have to make up your mind, and in the end there will be a vote. (In the end there is always somewhere a vote, either in corporate board rooms or at the polls!)

What can you do from the outside without meddling and still take a stand? *Mapping controversies* as we learned to do in sequence 4 is one solution. It happens that it is now slightly easier to use tools (often digital tools) to map out the range of opinions and the networks of experts dealing with any given issue. (Your own blogs designed for this course, might play a role in clarifying the issue for those you have followed).

While ordinary citizens cannot deal with all the details internal to an issue, if they have a good ear and nose for controversies, they might be fairly apt at detecting partisanship. This is the essential virtue of public debates provided they are well organized and fairly equipped with controversy maps: they allow bystanders to detect who might be more or less partisan than the other. Although there exist no formal rule for detecting partisanship, it is a feel that can be educated by multiplying the cases.

Partisan detection is essential because every party will be claiming to speak in the name of the Public Good — scientists in the name of Science, corporate interests in the name of Development or Wealth, administrators in the name of Health and Nation, but also militants of all sorts of hues and colors. This is the problem of our poor councilman in Hawaii: every one of his voters claims to know for sure and in no uncertain terms, what is good for the land of Hawaii. So what should he do? He should try to push every party to fly under one's own colors and to state their interest in full. In practice, it means pushing them to describe what we have learned to call a *cosmos*.

To become a citizen in matters of science and technology means that we should learn to sketch the architecture, procedure, participants and protocols of the *quasi-parliaments* where issues that concern a public have to be settled. It is not an easy thing since the shape of those issues and the forum in which they are treated vary enormously and very few of them look like the traditional institutions of politics. But they are parliaments nonetheless where representatives and spokespersons for the many parts of the worlds being mobilized and assembled. This is obviously the case with the issue of climate, but it is fair to say that it has become the case for nearly

every item of our daily life. So the task for this final sequence is fairly easy: draw the quasi-parliament around the thing, that is, around the issue, that you have chosen and define all the parties, their interests, their agendas and the possible compromises they could pass amongst themselves in order to compose a possible solution. Without exploring those quasi-parliaments, many of which are virtual while others are solidly entrenched, it is very difficult to define what a democracy is.

I hope that you have found this course refreshing and maybe also useful. I also hope that we will benefit from your feedback to make it better over the years.

Rhetoric and demonstration

I may surprise you, especially after what I've been telling you from the start, but to really understand the relationship between science and politics, it is first necessary to liberate oneself from the polemical definitions of scientific activity.

Philosophy, common sense, the almost unanimous opinion of instructors and researchers assert that it is necessary to choose: either interlocution— rhetoric—or demonstration, true science. It is that contradiction that interests me: by elementary empirical means, I lead students to discover that a supposedly impassable barrier can be crossed and recrossed a hundred times, without the slightest instrument, even though sharp minds maintain not only that the barrier is as imposing as the Great Wall of China but also that it must remain impermeable, to prevent the Barbarians from destroying Civilization. The situation somewhat resembles that of Renaissance seamen, whose travels proved it was possible to cross the equator without falling off the edge of the world, even as certain scholars were still asserting, eighty years later, that it was impossible.

Either you practice rhetoric or you make a demonstration. You have to choose, they say, between having the gift of gab and being right "for real." No distinction is more over-determined than that one. None is more solidly entrenched. And yet, I assure you, none is more contrary to the evidence! Oh, evidence, how many crimes have been committed in your name! What dark labor is required to see your brilliance! How many detours and folds and complications are needed to grasp your simplicity!

The Greeks invented two terms for these two kinds of evidence: epideixis for rhetoric, the famous flowers of eloquence, the art of deception and manipulation, those that blossom especially in the courtroom and in politics; and apodeixis for geometry, that famous indisputable necessity that gave us the adjective "apodictic," and whose rigorous chains of argument give rise to treatises and science manuals. The interesting thing is that these two activities, which are said to be in absolute opposition to each other, which people have pretended to believe were engaged in an age-old battle, have almost exactly the same etymology, a telling sign not to be overlooked.

There are not two sides but only one side with multiple branches, one of which is still called "rhetoric" and another of which ought to bear the name "the rhetoric of non-rhetoric." It would be simpler to place both under a single rubric, that of the unique, the holy, the grand eloquence, which could be defined as the art and science of speaking well, but with the reminder of how difficult it is to speak well of people—and especially of things. We will henceforth consider rhetoric and demonstration no longer in opposition to each other but as two of the branches of eloquence. It is now clear why Aristotle could say of rhetoric that it was "the necessary sparkle to the diamond of truth." The deepest meaning of the scientific humanities is that they consist of following all the tests capable of convincing or not convincing, all the ingenuity, all the apparatus, artfulness, all the finds, all the tricks, thanks to which one ultimately makes a proof self-evident in such a way as to close a discussion, allowing interlocutors to change their view of the matter, for which purpose they are assembled. You can see that we would have made a serious mistake if we had started with

the self-evident and the indisputable. And yet, it is truly a matter of arriving there. Evidence is never self-evident—at least at first; and as for the indisputable, it is always disputed, at least at first.

That manner of understanding the gradual elaboration of proofs and the tentative search for truth differs altogether from the usual stagecraft, which assumes a conflict of sorts between the forces of truth and those of prejudice and passion.→ In that other, widespread way of seeing things, one no longer describes the gradual transformation of utterances that end up being true and proofs that end up becoming self-evident: one acts as if utterances ought to have proceeded in a straight line from the start if only they had not been diverted from that path by schemes, treachery, misunderstandings, obstacles, deviations, and detours. The notion of composition is completely different. It is no longer merely the consequence of two sets of opposing forces, through which truth, with difficulty, clears a path. The forces of evil can only delay the forces of good. Dark rhetoric can only momentarily obscure the bright light of demonstration. When the demonstration ultimately triumphs, which, it is said, is inevitable, it has nothing more than what it had at the start.

I'm acting in bad faith, since I'm well aware that philosophers had excellent reasons for setting up a barrier between rhetoric and demonstration. They were grappling with monsters that they believed it wise to combat (recall Plato's struggle with the squawking, argumentative masses, with that impossible agora); or with monsters that did, in fact, need to be combated (think of the Vienna Circle in the clutches of the Nazis and Soviets). But these excellent reasons were, precisely, political and not at all scientific. That's the essential point: none of the distinctions between science and politics, between demonstration and rhetoric, have the aim of describing that engrossing phenomenon, the slow and arduous process of obtaining a scientific proof. The distinctions have only one aim: to construct a grand polemical history in the course of which the forces of reason are long combated by the forces of unreason, until the final victory—which is, moreover, inevitable. These distinctions are polemical, they are battlefield concepts. That battle may be justified, but if there's one thing it does not allow us to understand, it's science. If, as Aeschylus said, "In war, truth is the first casualty," then, in the polemic about science, the truth about science is the first casualty. That's why I've warned you several times that agreeing about its history was neither possible nor desirable.

What is a representative government if issues cannot be represented?

There is now general agreement that many societal and political issues have become scientific and technical as well. There is also general agreement that some sort of double competence is needed to comprehend those mixtures of science, technique, law, economics, organizations and politics. Hence, the new importance given to the theme of "scientific humanities".

But the agreement stops when is raised the question on how to produce a competence on science and technology in the society. Whereas it is assumed, in political theory, that citizens were sufficiently enlightened to pass judgments on the issues at hand when those states of affairs were close enough and of enough common sense, there is no consensus on how to pass judgment and allocate crisis when vast amounts of conflicting technical data are brought in the dispute. This is especially true when scientists and experts themselves seem to disagree on the issues. It is impossible in that case to turn to their consensus in order to "black box" at least the technical aspects of the disputes. It is clear that paying lip service to the "participation" of citizens and to the importance of "technical literacy" is not enough either.

The major flaw in all the discussions about bringing the students in closer connections with the more esoteric and specialized aspects of the issues on which their future depends, is that there has been little effort to equip the citizens with new tools to grasp those issues in a way adjusted to the new situation. Most political theory in Science in Society relies on the idea that the normal equipment of citizens, as it has been dreamed of in the early days of representative governments, will function as well in the new age of ecological and technical controversies: common sense and open discussion will suffice or else relying on expertise about the technical aspects of the dispute. Even though it has taken about two centuries to produce a partially functioning (or largely dysfunctional) practice of citizens' involvement in representative governments, not much energy and intelligence has been put on how to represent scientific and technical issues for the larger public to pass judgment on them.

The word "representation", as it is used in the general theory of representative governments, has not been renewed sufficiently to bring also the question of how to represent controversies about science and technology. And yet a polity, even if it is nominally democratic, ceases to be representative if it is unable to re-present, that is present again in a graspable way the issues at hand. In other words, too much effort has been put in the procedures by which citizens should be brought in collective disputes, and not enough in the practical tools through which the issues themselves can be figured out in a way understandable to all those concerned.

This might surprise those who believe that democracy can be obtained at no cost and rely only on the normal cognitive resources provided to everyone by nature. This would however be a major mistake. There is nothing natural, spontaneous, and costless in having an opinion in political arenas. The whole slow and painful history of citizenship and representation shows how arduous, convoluted and depending on practical objects has been the construction of the public sphere: from ballots to coffee houses, from the press to election

procedures, from demonstrations to propaganda, political history is largely the history of the practical innovations that allowed to produce this artificial situation of a citizen able to have an opinion and to pass judgement and accept as legitimate a decision that put him or her in the minority. What is true of political proper is even truer of scientific and technical controversies for which there is no precedent, where the facts of the matter are most obscure, when experts have failed to provide a consensus. The idea that we could "naturally" come to agree if only we could all be "reasonable" and "sit at the same table" is not only naïve, it is dangerous as well, since it does not pave the way for anything more than a cosmetic and superficial involvement which in the end delegitimates political representation in general. Science needs a public, but this public is a problem.

SEQUENCE 8: ADDITIONAL FEEDBACK ON SELECTED BLOGS —AND FINAL COMMENTS

Should we prescribe

Gamifying example

Project Apollo dam

Anthropocene and satellite debris

FINAL COMMENTS