Progress

Class 3 - Science

Kevin A. Bryan - Toronto Rotman - Oct 1, 2025

Notes after class are in red

Thus far

1) A definition of progress

2) Do all folks (and did all folks) believe in it?

3) What happened in the IR?

Science ofers a largely unexplored hinterland for the pioneer who has the tools for his task. Te rewards of such exploration both for the Nation and the individual are great. Scientifc progress is...essential...to our better health, to more jobs, to a higher standard of living...

From "letter of transmittal from Vannevar Bush to the President", July 1945. Bush was an MIT professor, founded Raytheon, invented an early computer, Dean of Engineering at MIT, wrote an essay "As we may think" that inspired much of the internet (worth reading, directly influenced hypertext and the mouse in the "Greatest Demo Ever"!), chairman of NACA (which becomes NASA), then in charge of OSRD for US science policy in WW2 where he initiated the Manhattan Project (played by Michael Modine in Oppenheimer).
Also had Claude Shannon as his student, "a master craftsman at steering around obstacles, whether they were technical or political or bull-headed generals and admirals" (his NYT obituary), AND maybe most influentially writes The Endless Frontier which is the basis of basically all global govt science policy, idea of "basic research", and directly led to the NSF in the US.

Recall from Class 1:

Such is the object of the work I have undertaken; the result of which will be to show, from reasoning and from facts, that **no bounds have been fixed to the improvement of the human faculties**; that the pefectibility of man is absolutely indefinite; that the progress of this perfectibility, henceforth above the control of every power that would impede it..."

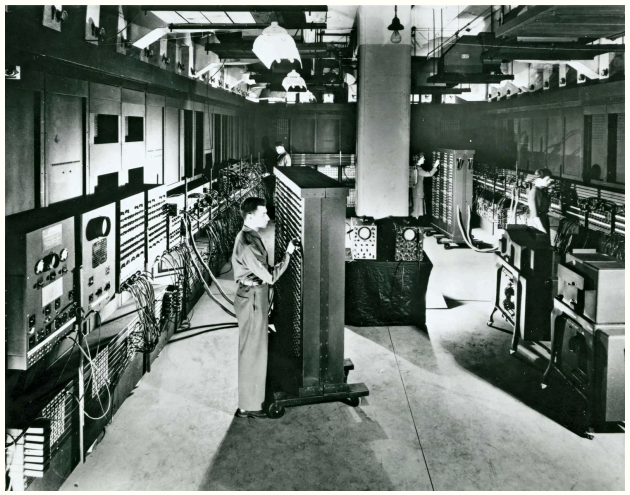
Condorcet, *Esquisse*

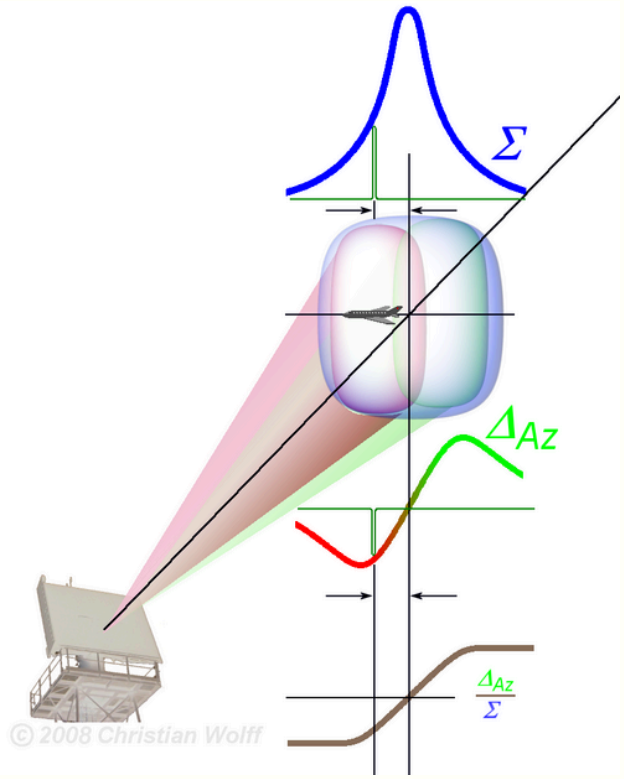
Is science unique in that it has no bounds? Cities congest, liberty can only be so maximized, culture has limits...so is science the fundamental firmament?

Today:

1) Does science matter for progress (human standard of living can and will improve from purposeful human action)
2) If so, why and how? What matters?

But let's start with a question. Can AI speed up the "rate of science" consistent with those goals? Why or why not?





Flu vaccine *ENIAC* *Monopulse radar*

Some famous WW2 inventions: the modern flue vaccine and radar, early computers, the nuclear bomb, mass produced penicillin, DDT, etc.

V. Bush responding to idea from Kilgore for an applied, targeted govt science program, geographic spread

Bush wants autonomy, "basic research", top scientists get $

The fundamental shift with huge implications for future science policy was the focus on autonomy and Bush's definition of basic reearch as "research performed without thought of practical ends". Science policy not as national development a la agricultural extension services that set up locations around the country to do testing, but instead as "give the best scientists money to do research the private sector would never do then you'll have the base material of future applied invention".
Note, as Rosenberg does, that it's not obvious at all that the private sector will refuse to do *all* basic research in this definition!

Before WW2, *no country* had large extramural research funding.

During WW2, 9bln (today's US$) in extramural R&D

Today, US alone > 100bln/year

In a sense, the WW2 experience of rapid progress led FDR (and other world leaders) to see a greater role for government science policy.

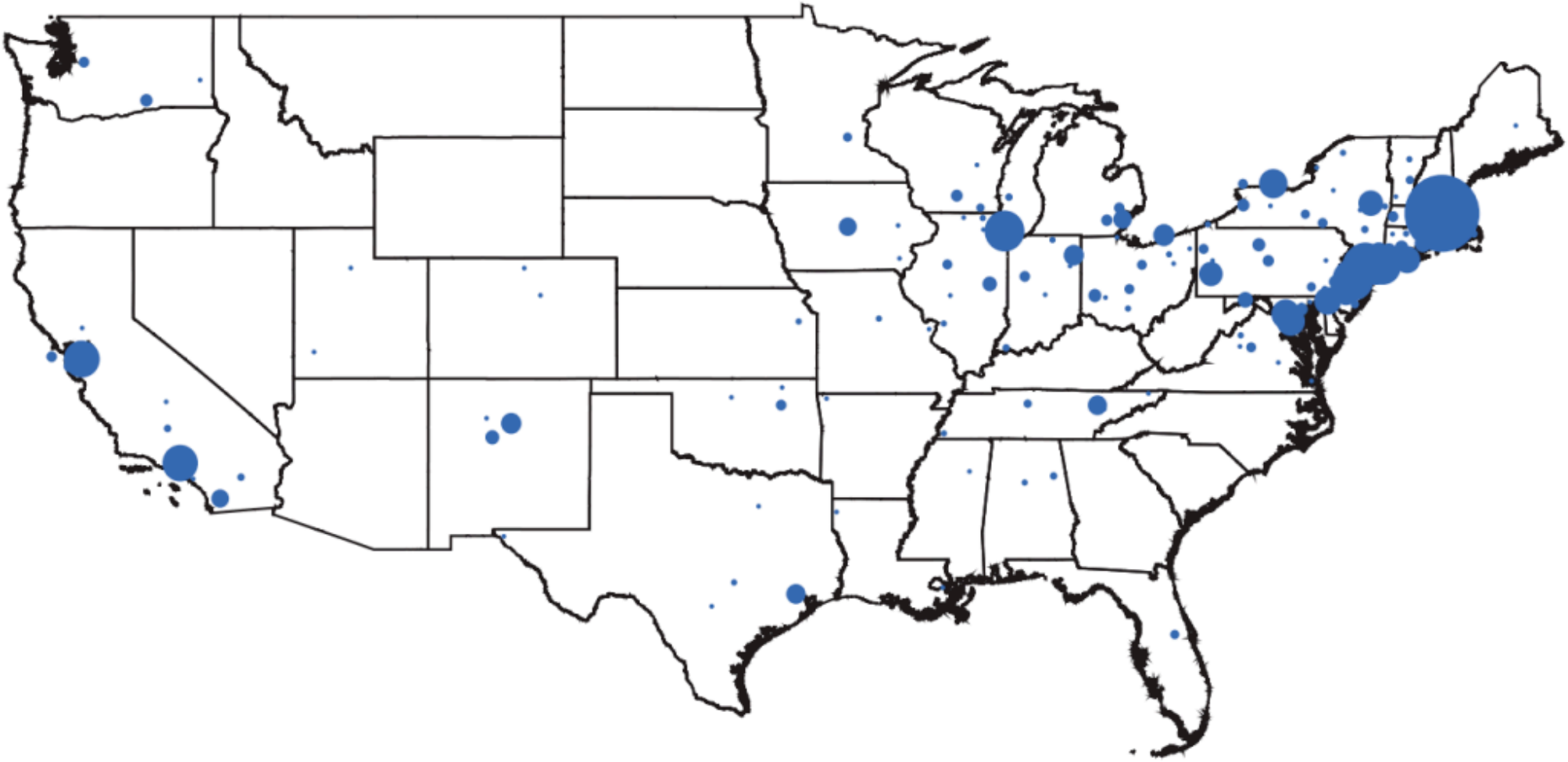


FIGURE 2. GEOGRAPHY OF OSRD-FUNDED INVENTION IN WORLD WAR II

County-x-Field that gets OSRD contracts -> 50% more patenting 25 years later, clusters of innovation, even compared to similar pre-war places. (Also, USSR Science Cities, Apollo)

From Gross and Sampat (2025). Huge spillover benefits for regions in WW2 (though these types of regional innovation policies have often failed - as we'll see when study cities later in the term!). You saw similar benefits from Apollo (Kantor and Whalley 2025) and the Soviet "Science Cities" (still relatively wealthy in today's Russia).

How else could science be funded?

Charity (but the numbers are so small compared to total govt funding). The private sector (but they will fund what they can "appropriate" - meaning earn profit from the results of the research - and a lot of science spills over to other folks or people doing work in completely different fields.
For instance, research on the Gila monster, a lizard, led to Ozempic! https://www.nytimes.com/2025/02/16/science/gila-monsters-cryptosporidium.html

Is science unique among economic activity in its positive spillovers? What do we mean by that? Which kinds of science?

Probably. Our best estimates on the social return to science versus the private return are somewhere between 2 and 5 times. That isn't to say no one in the private sector will do research - they do, especially when institutions allow them to capture rents from the research results. But positive externalities of this size are hard to incentivize with pure laissez faire markets.

Basic research is performed without thought of practical ends. It results in general knowledge and an understanding of nature and its laws

V. Bush, The Endless Frontier

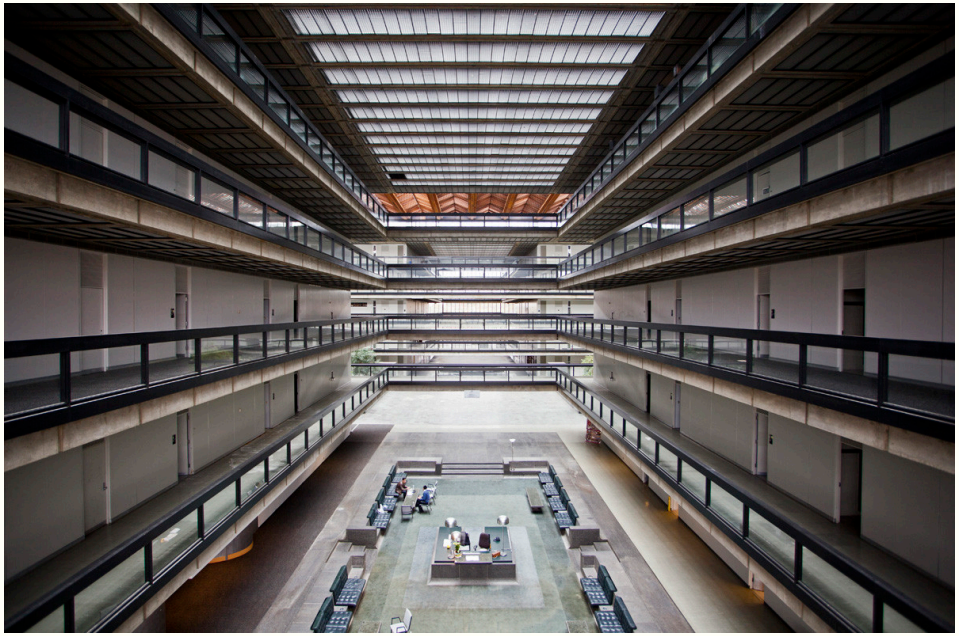
Bush again: "The scientist doing basic research may not be at all interested in the practical applications of his work, yet the further progress of industrial development would eventually stagnate if basic scientific research were long neglected. One of the peculiarities of basic science is the variety of paths which lead to productive advance. Many of the most important discoveries have come as a result of experiments undertaken with very different purposes in mind.
Statistically it is certain that important and highly useful discoveries will result from some fraction of the undertakings in basic science; but the results of any one particular investigation cannot be predicted with accuracy. Basic research leads to new knowledge. It provides scientific capital."

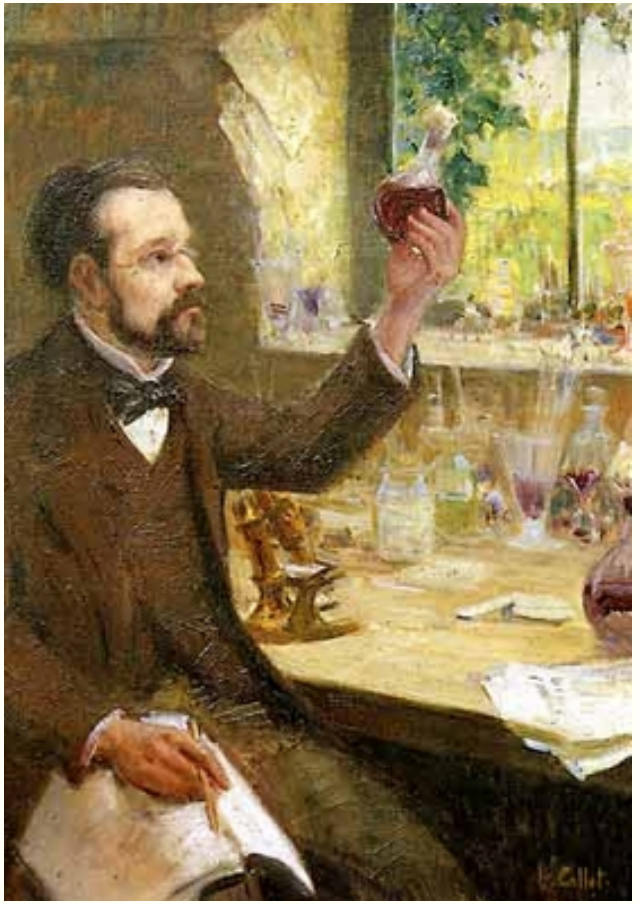
The 'linear view'

With some notable exceptions, most research in industry and in Government involves application of existing scientific knowledge to practical problems. It is only the colleges, universities, and a few research institutes that devote most of their research efforts to expanding the frontiers of knowledge.

V. Bush, The Endless Frontier

Does this justify *govt* funding? That is, is it really just basic research which is underappropriated? Appropriation means the fraction of total social value created that is earned as profit (that is, value creation vs. value capture). Some basic research can be appropriated, as we'll see in a few slides and as Rosenberg explains.
And some very applied work is hard to appropriate (e.g., early stage medical trials whose failure is very informative for other pharma companies).





Bell Labs and Pasteur's real goal

Why does anyone do basic research despite the spillovers? Market power and sometimes first-mover advantage. But also absorptive capacity (But [the model of "ideas on the shelf to pull from freely" is seriously flawed because it frequently requires a substantial research capability to understand, interpret and to appraise knowledge that has been placed upon the shelf - whether basic or applied.) Pasteur was working on taste issues in wine when he discovered what became the field of bacteriology.

The cost of maintaining this capability is high, because it is likely to require a cadre of in-house scientists who can do these things. And, in order to maintain such a cadre, the firm must be willing to let them perform basic research.) And sometimes byproducts (Karl Jansky working at Bell Labs - the telephone company's lab - on static finds a third source that is not storms - and creates radio astronomy). And Arno Penzias and Robert Wilson, also at Bell, were hired for pure research on astrophysics out of hope what they found might prove useful to Bell's problems (Bell was big and had market power if they were solved!) - they win the Nobel for finding the cosmic background radiation predicted by theories of the Big Bang!

Scientific progress on a broad front results from the free play of free intellects, working on subjects of their own choice, in the manner dictated by their curiosity for exploration of the unknown.

V. Bush, The Endless Frontier

How do we prevent scientists from wasting time and money in this case?

What do scientists actually *do*? That is, what is the thing we call science that may lead to progress?

Give me a definition...

Latour and Polanyi both point out that scientists are *not* "testing hypothesis and reporting any contradictory findings" as a naive reading of Karl Popper or your high school science class might suggest!

And you thought Vannevar Bush was impressive; here's Michael Polanyi

Michael Polanyi's son won the Nobel in Chemistry (one of U Toronto's few prizes!), brother Karl Polanyi is a famous economic sociologist (The Great Transformation about how markets and the nation-state come together and markets are embedded in rules).
Michael was a great chemist and mathematician who dabbled in social science so much despite having multiple Nobel-winning science students that he becomes more famous for the social science ("spontaneous order" was his term, picked up by Hayek, as is "tacit knowledge" - much of what we know is like riding a bike, we can do it, but can't explain why we can do it, and that includes science).

Polanyi's "science as jigsaw puzzle"

On a jigsaw, would you give a hundred copies to a hundred people in different rooms to solve independently? No, too slow. Or tell each scientist ex ante which piece they are "in charge of"? No, they might see how to place a different piece. Instead, we have a "Republic of Science" that allows us to use local information (things only we know) and tacit knowledge (things we know but can't explain) to solve scientific problems while using peer evaluation and publishing to coordinate.
That is, for Polanyi, science is like the market economy: unplanned 'spontaneous order'!

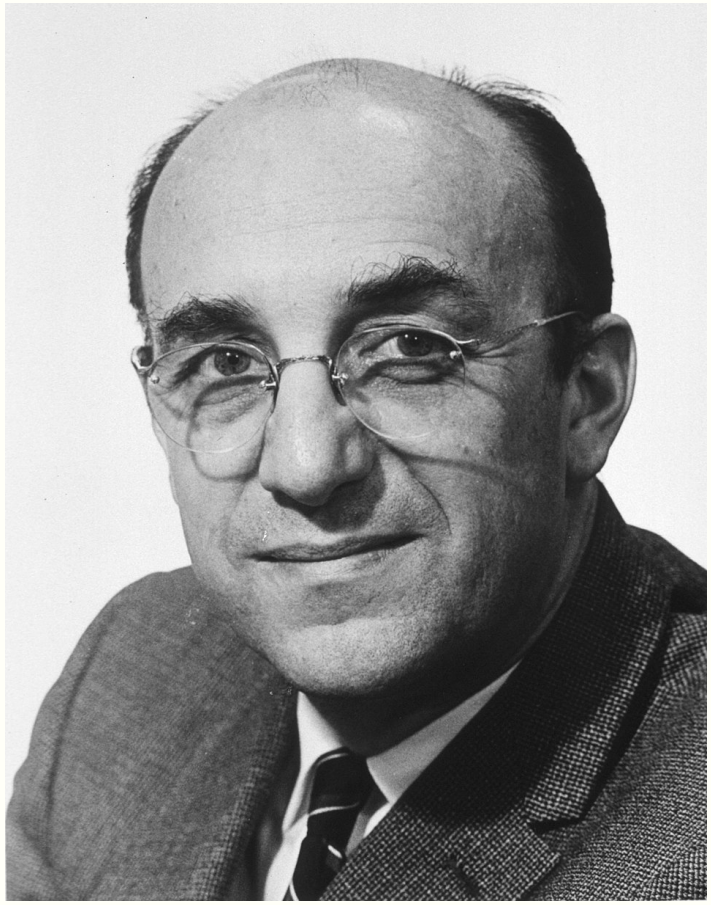
Local knowledge + "tacit knowledge" = spontaneous order

"The Republic of Science is a Society of Explorers. Such a society strives towards an unknown future, which it believes to be accessible and worth achieving. In the case of scientists, the explorers strive towards a hidden reality, for the sake of intellectual satisfaction. And as they satisfy themselves, they enlighten all men and are thus helping society to fulfil its obligation towards intellectual self-improvement."

...one's person never becomes fully involved either in a problem that is much too hard, nor in one that is much too easy. The line the scientist must choose turns out, therefore, to be that of greatest ego-involvement; it is the line of greatest excitement, sustaining the most intense attention and effort of thought.

Polanyi, Republic of Science

Scientists do not waste time/money as much as you think because their ego wants them to solve important problems - it is more fun to do so! Of course, the worry here is that there are many less-fun intermediate steps we may need someone to solve...

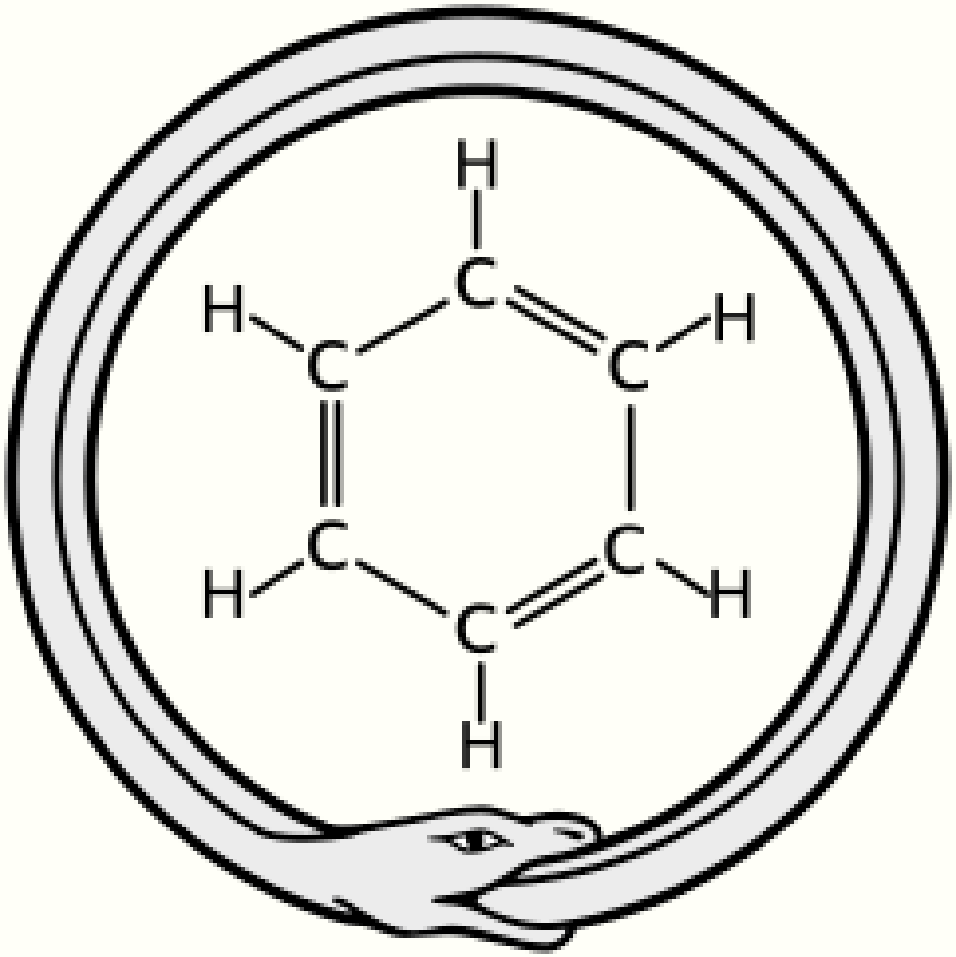


Bruno Latour and Roger Guillemin

Latour is an absolutely wild French anthropologist. He got the Salk Institute in California to let him shadow a lab in the 1970s - and tried to learn what scientists do like an anthropologist! The lab he was in happened to have done work at this time that then won a Nobel Prize.

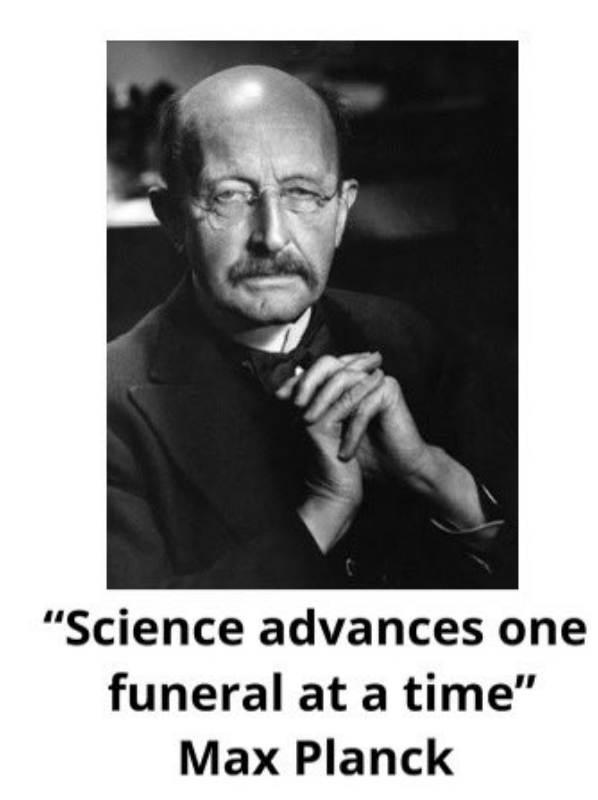
Are the rituals and norms in the latter so much easier to understand that in the former?

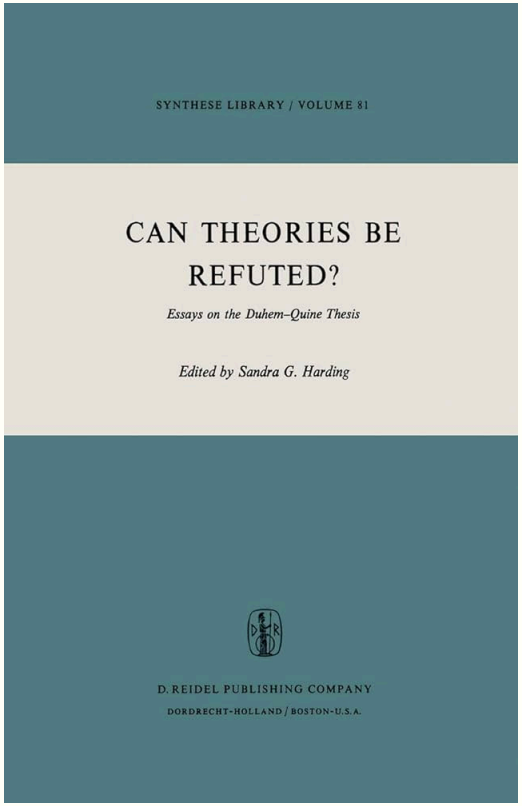
Left, Malinowski in the Trobriand Islands of Papua New Guinea taking notes on the norms, rituals, daily life. Latour's idea is that we can understand science better by doing exactly this with scientists.



Stories of Eureka moments vs. real science

Mostly we learn about scientists from their biographics (everything is a "Eureka moment") or gossip/scandal/"fun story" type tales. E.g., Kekulé, who finds the structure of benzene, a hugely important discovery in chemistry, claims he figured it out from a dream where he saw an Egyptian ouroboros, a snake eating its own tail. He then woke up and say, aha, the double hull structure of benzene!
But you and I don't dream of snakes and Eureka our way to chemical structure - of course, Kekulé has already done 99% of the work in the lab. That's what Latour wants to observe: how does a year of work, people carrying paper with dot plots from one office to the next, observing strange things, somehow become a five page paper "reporting the results".





The social aspects of science

If science is purely technical how can Max Planck be right? When others objected to Gaileo's claim he saw mountains on Mars in his telescope by arguing maybe they were telescope artifacts, who is to say which is right? How much "skepticism" is warranted for progress to happen? What social settings help science along?

A series of simple experiments were published in June 1947....purporting to show that hydrogen atoms striking a metal wire transmit to it energies up to a hundred electron volts. This, if true, would have been far more revolutionary than the discovery of atomic fission by Otto Hahn. Yet, when I asked physicists what they thought about it, they only shrugged their shoulders. They could not find fault with the experiment yet not one believed in its results, nor thought it worth while to repeat it. They just ignored it.

Polanyi, Republic of Science

Is this sensible? The science you were taught as a kid?

Is science really just based on "what other scientists think plausible?" And this works? Science advances one funeral at a time partly because older scientists control the journals and the hiring and the funding...but partly for good reason, because they have developed an intuition for what is likely to be "real" and what isn't.
Note these social aspects are hugely important - and getting the balance right between skepticism and progress is critical for science to contribute to progress.

Can science advance according to technical rules alone?

What would an AI lab do? Is the artifact called the "paper" as important?

No, Quine's "two dogmas" + polanyi's tacit knowledge mean that scientific advancement requires many social choices. But what if we just gave AI not the paper but all the raw data, all the intermediate experiments, video of what happened for 24 hours a day: could the AI more quickly separate out "this is likely real" from not? Do we need new scientific institutions and norms to make this easier?

Polanyi: In January 1945...We were asked about the possible technical uses of Einstein's theory of relativity, and neither of us could think of any.

But are we sure basic research matters this much? "The capital of innovation"? Or are we self-interested?

It is definitely true that undirected research, with no applied product in mind, often leads to amazing applied breakthroughs such as nuclear energy (including downsides and ethical issues, as we also see with nuclear!). But this is ver hard to measure - of course scientists often prefer doing basic research, so they might be self-interested in claiming its importance.
But V. Bush ran large-scale applied work, including kicking off the Manhattan Project, and even he things that without the basic research, we couldn't get the modern inventions we need to progress - that is, without basic research, we "run down our capital" just as a factory that didn't clean and upkeep its machines can't product good products.

So, a survey. You are asked by a friend (or policymaker!) "how important is more and better science to progress?"

Let's vote: 1-5, where 1 is "not at all" and 5 is "I imagine the most important factor we'll discuss this term". We'll keep track of these votes as we go!

Result: 1/5 (0), 2/5 (0), 3/5 (8), 4/5 (13), 5/5 (9). Average: 4.03. Explanations for 3 from a student: "I would have said 5 except for the human factor. Human institutions limit how much science can affect progress." And for 5: "Thinking about how our lives differ from ancient Kings, the biggest difference is science-driven innovation, like penicillin."

Faced with the outbreak of the French Revolution, Edmund Burke denounced its attempt to refashion at one stroke all the institutions of a great nation, and predicted that this total break with tradition must lead to a descent into despotism. In reply to this, Tom Paine passionately proclaimed the right of absolute selfdetermination for every generation.

Polanyi, Republic of Science

We do not derive everything from first principles, science or otherwise. This debate is the core of progress.

Your term paper

Prior to *Class 6*, you will give me a précis of your term paper.

There are no exams in this class.

Goal: you explain *using new research* why some specific moment of progress happened.

GPT exists. You will want to use the phone & the stacks