Chapter 7
Philosophy, Engineering, and the Sciences

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Abstract Philosophers aim for universal truths, but in that effort, when the empirical details are ignored, the philosophical story may end up missing the mark. Here it is argued that when attention is applied to the details, the Old Story that engineering is applied science falls apart. It is further argued that attempts to establish some kind of epistemic authority for science over engineering are simply misguided.

7.1 Introduction; Problems with the Old Story

Philosophers don't like details when it comes to facts. They are perfectly happy to worry to death the myriad meanings of "meaning". But when it comes to working though the factual components of what are fundamentally empirical claims the work is slim. And because some of what looks like a philosophical claim, but for what is really an empirical claim, the results of not finding out what is really the case can result in some philosophical claims appearing rather stupid. One I have in mind concerns the relation between science and technology, or more specifically between science and engineering.[1] In this chapter I look at something that has not been looked at by philosophers: the real world interaction between doing science and engineering. What I argue is that contemporary science cannot be conducted until some serious engineering is already in place. This may not be news to scientists and engineers, but it is news to philosophers, especially to a distinct group of philosophers of science who tend to think of science in isolation from the real world. These philosophers are concerned with such issues as the logical structure

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[1]Talking about "technology" as if it is a thing in itself is unhelpful. I argue this case in my 2000 book. Likewise for "science". In that work I argue for the need to look at some category of practitioners comparable to scientists if we are to learn anything of value. I lay out some criteria that lead me to identify engineers as the technological counterpart to scientists.

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of explanation or the role of probability in the logic of confirmation. But the results have nothing to do with understanding how science really works, meaning by that how scientists go about their research.

We all know the *old* story: the scientists do basic research and technologists (for our purpose here, specifically engineers) apply it. This is a troublesome account because something about it doesn't ring true. In particular, *how* does the move from basic science to applications take place? The results of basic scientific research are published (when they can be published[2]) in very specialized venues using very specialized language not readily accessible to most mere mortals. I not even suggesting that engineers can't read this literature, but simply asking if, given their other responsibilities, can they find the time to do so? It is not clear to me that having made some discovery or other that the scientist picks up the phone and tells his engineering colleague "now you can do this or that". Nor is it clear that engineers keep close track of the burgeoning scientific literature to find out what's new and have immediate "ah, ha!" moments, or even later, "duh" moments. There is also the complex problem of intellectual property rights, finding interested investors, manufacturers, distribution routes, etc. So, in the end, the old story is not only a false story, but highly misleading. I want to tell a different story. The point is this: if the technological infrastructure of science is, in part, the product of engineering research and hands on design and inspection, and the research that makes it possible to build both labs and instruments comes out of engineering research, then engineering research is just as fundamental as scientific research. But there is more, for the result of looking at the relation between science and engineering through these lens results in seeing that conceptualizing the issue in terms of who is subservient to who, science or engineering, is wrong from the start.

Although he hasn't said this explicitly, the argument I am proposing is congenial to the views Peter Galison develops in his *Image and Logic* (Galison 1997). In particular, I have in mind his distinction between the inner and outer lab, especially the outer lab. I take Galison's outer lab to be amenable to the notion I introduced in my *Thinking About Technology*, the technological infrastructure of science. What the technological infrastructure idea is supposed to capture is the range of things that make the doing of science possible: funding agencies, universities, private corporations, technicians, labs, graduate students, etc. I will proceed by returning to my motivating issue, which is whether or not it is correct to think of the relationship been science and engineering as one of subservience. I am going to begin by looking at a couple of examples and argue for a more encompassing view.

7.2 Examples of Applied Science

Some cases are easier to understand than others – i.e., some discoveries more readily suggest applications than others. This can happen is many ways, but looking at two

[2]Restrictions on the dissemination of research results often are found when scientific research is conducted for the military or by private laboratories funded by industrial or pharmaceutical companies.

examples will yield the general idea. In the first case a scientist can be looking to achieve a specific end which itself is an application. Thus, consider a microbiologist working on transmission of micro-organisms through ground water, who sets out to construct a bug that will eat oil. Let's say he started on this project after hearing of a particular disruptive oil spill when a tanker went aground. After successfully creating the oil eating bug, he sets up his own company, rents some space at the Virginia Tech Corporate Research Center, hires some graduate students to make the things, contacted oil companies to inform them of the product and is now making money hand over fist.[3] What is missing from this picture is an engineer. Moreover, while a close examination of the process employed to create the bug deeply resembles a classic engineering design process, complete with feedback loops, our researcher is a biologist, not an engineer. In this case, the line between scientist and engineer is clearly blurred, given the old story. But, the positive result of this new story is that it opens up the possibility that in some cases, the so-called scientific method is more like an engineering design process than some idealized and false view of how scientists do their work. Here we started with a product in mind and after considering the restricting parameters – the end product must be inexpensive to produce, must pose no danger to the environment, must be easy to transport, etc. – proceeded to propose a mechanism, test it, refine it, retest, etc.

A second example of how scientists connect to applications is the "opps!" case. This occurs when a mistake is made or an accident occurs in a lab and an unintended result comes up that has immediate applications because of the result itself. The process by which this discovery makes its way into the public domain may or may not involve engineers down the road, but the awareness of its applicability does not. For example consider the case of penicillin. The following account is from the Discovery Channel web site.

> Alexander Fleming discovered penicillin in 1928. Of course he wasn't actually looking for it at the time- he was researching the 'flu. He noticed that one of his petri dishes had become contaminated with mould. Other scientists may have recoiled in horror at this result of shoddy work practice, but not Alexander. He chose to investigate.
> Whatever this intruder was, it was killing off the Staphylococcus bug - a bug causing everything from boils to toxic shock syndrome. Eventually he identified it as the fungus Penicillium notatum and it put the knife into Staph by means of a chemical that destroyed its ability to build cell walls. Being a scientist, he thought long and hard about what to call this new chemical, a chemical released from the fungus Penicillium notatum.
> That's right he called it penicillin. Nice one Alex. Unfortunately naturally occurring penicillin isn't very stable and thus not very useful. Fleming had found a wonder drug, but couldn't do much with it. Luckily just three years later two Oxford researchers created a stable form and today it's one of our most important tools in the fight against disease.

Consider now an example of a discovery that was delayed in its application and why.

This account is taken from Wikipedia – thereby acknowledging all my student's resources.

[3] This description is based on a real episode.

> In 1968, Dr. Spencer Silver, a scientist also at 3 M in the United States, developed a "low-tack", reusable pressure sensitive adhesive. For five years, Silver promoted his invention within 3 M, both informally and through seminars, but without much success. In 1974, a colleague of his, Arthur Fry, who in a church choir in North St. Paul, Minnesota, was frustrated that his bookmarks kept falling out of his hymnal. He had attended one of Silver's seminars, and, while listening to a sermon in church, he came up with the idea of using the adhesive to anchor his bookmarks.[1] He then developed the idea by taking advantage of 3 M's officially sanctioned bootlegging policy. 3 M launched the product in 1977 but it failed as consumers had not tried the product. A year later 3 M issued free samples to residents of Boise, Idaho, United States. 90% of people who tried them said that they would buy the product. By 1980 the product was sold nationwide in the US and a year later they were launched in Canada and Europe[2]. Post-It Notes are produced exclusively at the 3 M plant in Cynthiana, KY. In 2003, the company came out with Post-it Super Sticky notes, with a stronger glue that adheres better to vertical and non-smooth surfaces.

The point of these two examples is to suggest that to understand the move from scientific discovery to practical application needs more than hand waving at science and technology as such. We have already observed that the process of going from a discovery to a practical application is more complicated that the standard story would lead us to believe. While complicated, it nevertheless seems possible to spell it out using the standard story. However, I want to argue that even doing so will still give us a skewed picture.

7.3 A Transcendental Argument for Engineering Priority

The picture is skewed because it starts with the scientist. It suggests that the scientist does research and comes up with discoveries, but it does not fill out the picture as to what is entailed by saying the scientist does research. To resolve this we need to pursue a classic Kantian transcendental argument: what does the scientist need in order to do what he or she does?

In order for a scientist to conduct research, he or she generally needs a lab. It can be as simple as a computer, or as complicated as a radio telescope, but to say a scientist conducts research entails that there is a context in which that research is done, even field scientists who study the behavior of the great apes treat the environment in which the apes live as their lab. Once we open that door, the entire picture changes.

In *Thinking About Technology* I introduced the notion of *the technological infrastructure of science* as "an historically determined set of mutually supporting artifacts and structures that enable human activity and provide the means for its development" (Pitt 2000, p. 129). As noted above, parts of this complex are the labs, graduate students, technicians, instruments, universities, and funding agencies that make modern science possible.

Consider what is involved in hiring a new scientist at a typical American university. I am not talking about the hiring process, i.e., the means by which the individual hired is selected – but rather the rest of the process that must be completed before the offer is accepted: the support package offered to the new potential hire as an enticement to accept the offer. No active researcher would think of accepting a position without being guaranteed a lab, i.e., a particular space and start up money to equip the lab with the appropriate equipment needed to conduct his or her research, to hire a technician or two or three and to support at least a couple of graduate students. The typical "start-up package" at my university for a new Ph.D. in one of the sciences or in one of the areas of engineering, coming out of school and off a two year post-doc is approximately $400,000. It obviously gets way more expensive for senior researchers.

Now let us unpack this a bit further. Laboratory space is expensive. Depending on the research to be done, there will be a water supply and sinks, exhaust hoods, computers, isolation spaces, etc., all housed in buildings meeting more stringent building codes (meaning costing more to build) than your typical classroom building. The differential here just for the costs of the buildings is $50/square foot for a classroom building versus $150/square foot for an unequipped laboratory building. Doing science is expensive.

Second, part of the start-up package involves the money needed to fund the research. But it is also money that provides the time for the researcher to develop a research program and to write grant proposals to support further research once the start-up monies run out. That means there have to be sources for that funding. I would argue that the sources of funding, like the United States' National Science Foundation and the National Institutes of Health on the public side and various foundations on the private side also constitute part of the technological infrastructure of science. They are enabling systems.[4] Moreover, by virtue of having the money and issuing calls for proposals in certain research areas on certain topics, they not only enable scientific research, but to a large extent they control its direction. In the United States, under the G.W. Bush administration, federal sources of research funding could not fund stem cell research on strains of stem cells recently developed. This had an interesting effect in two directions. 1. It is forced certain kinds of research to be suspended or terminated for lack of funds. 2. It also pushed individual states like California to appropriate the funds themselves for such research, thereby putting them in the position to attract researchers in these areas away from states where they cannot do their work and making the universities and research centers in California a major force in this area. So funding sources make a difference in how science is done and what kinds of scientific research will be done and where it will be done. The picture of how scientific research is done and why is getting messy.

Let us return to the lab – for convenience sake let's make it a university lab. The picture sketched above is too simple – we don't just give the new researcher a lab and some money. The buildings have to be designed, built, and inspected to meet building codes and certain specifications. Instruments have to be designed and built. In short, not only are the funding agencies needed, the engineers who translate

[4]See Fink (2004) for some hard data on these issues.

architects' designs into buildings and who make sure they meet building codes, as well as the engineers who design and oversee the building of instruments are essential infrastructure components for scientific research. The materials that are used in the buildings are the product of engineering research for the most part, and that research requires the same kind of support as scientific research does – labs, technicians, graduate students, funding agencies, etc.

To be even a bit more specific, the spaces where scientific research is done do not simply appear out of nowhere. It is designed space. And then it is built space. I am deliberately making a distinction here between designing the space and building it. It actually needs to be a threefold distinction: designing the space, figuring out how to build it, and building it. Architects, if they figure into this process at all in a significant way, work in the first part, designing the space. For the most part, the most significant part of the work involves figuring out how to make the proposed design work – and that is an engineering job. Architects are notorious for drawing lines that appear to connect and leave it up to engineers and builders to figure out how to actually make them connect. It is of no small note that the most successful architectural firms today - what are called full service firms –involve both architects and engineers in the process of getting a building from plan to fact, sometimes they also supply the builders. So, the very spaces in which scientific research is conducted is heavily influenced by engineers. But there is more, for the materials used to build these spaces are constantly being improved thanks to engineering research into materials. And that research is conducted in much the same way scientific research is – in specially designed spaces, and so the cycle spirals upward and beyond. Peter Galison's account of laboratory design in *Image and Logic* speaks directly to this point (Galison 1997).

What engineers do and how they do it, to coin a phrase, is fundamental to what scientists do and how they do it. So far I have only addressed the spaces where scientific research occurs; if you will, the building of the spaces. But if we also look inside the science lab, we find the footprints of the engineers all over the place. Maybe not in labs of the gorilla researchers, but in the labs in the buildings we have been discussing we find instruments. Sometimes instruments are designed and built by scientists. If you will allow the anachronistic use of the term "scientist", when we consider Galileo the scientist, then we also have to contend with Galileo the instrument maker. One of the sources of income he relied on was the sale of instruments he not only invented, or made popular, but also built and sold, such as his military compass and his telescope (Drake 1978).

And it is well known that many contemporary scientists build their own experimental apparatus, pulling this and that off the shelf, which is one of the things that makes replication of experimental results so difficult.

Nevertheless, when it comes to buying equipment from commercial suppliers to equip your science lab, engineers are involved up to their elbows. For in the production of standardized lab equipment engineers play a major role, for these instruments are their provenance (See Baird 2004). In short, the contemporary scientist could not do her job without the engineer. There would be no appropriate space in which to work. The development of quality materials would be greatly delayed. If anything, there would be fewer and more poorly made instruments as well as whatever else is needed to fill out a functioning lab, instruments needed to conduct that work without engineers working independently.

This is not to say that from the beginning of time, engineers were central to the doing of science. The thesis I am reaching for is this: *modern* science relies on this technological infrastructure, in which large components involve work in which engineers play a major role. As historical backdrop it would be an interesting doctoral thesis to trace the historical development of the split of *scientia* into science and engineering. Something obviously happened in the 16th–17th century. The *media scientia* were already recognized as doing something applied – both Da Vinci and Galileo were often employed as what we would today call engineers working on military fortifications while doing multiple other things, like painting and writing music, etc. But to talk that way may be too simplistic. Why should we assume that there was a split into something like science and engineering from something like the *media scientia?* Maybe things don't happen that neatly. If you are looking to draw straight lines ignoring what is actually going on, you can probably do so. But straight lines are boring.

7.4 Conclusion

So the bottom line here is that simple generalizations about the relation of this to that need a more nuanced historical analysis that goes deeply behind the surface to uncover what really is going on. I hope I have provided a schematic for the kinds of details that need to be examined – it is not presented as the full story by any means. There are a couple of problem areas here that we need to be sensitized to: (1) the reification of human activities – i.e., science as somehow something that doesn't take place in a time and place being done by people; (2) Galison's idea of how science changes, not all at once, but different parts changing at there own pace, works here; (3) the politics of priority – this has not been addressed in the current chapter, but it is worth raising, even in passing: as any sociology undergraduate major will tell you, there is a competition in society among groups for some kind of social recognition. In our story it is alleged to be between science and engineering. But that just may be the wrong way to frame the discussion. It assumes there are these *things* that are called *science* and *engineering*, when if fact they are complexes of great complexity. Simplifying the rhetoric makes it easier to present a case for superiority or priority, but presenting the case does not make the case. It is one thing to talk about the miracles of scientific discovery, and quite another to address the particulars of research into the biochemical structure of stem cells. There is much to be said about the rhetoric employed in the politics of the funding world. And we should make no mistake about it, it is all about money when the fancy language is put aside. In the end questions of priority and subservience seem to boil down to who gets the money to fund their favorite research projects. And what people do and say to get that money is a topic of endless fascination. That is one reason why we should address the particulars, the people and what they do. The other is that science and engineering simply don't do anything, people do.

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References

Baird, D. 2004. *Thing Knowledge; A Philosophy of Scientific Instruments.* Berkeley: University of California Press.

Drake, S. 1978. *Galileo at Work*. Chicago: University of Chicago Press.

Fink, I. 2004. Research Space: Who Needs It, Who Gets It, Who Pays for It? *Planning for Higher Education* 33(1): 5–17.

Galison, P. 1997. *Image and Logic*. Chicago: University of Chicago Press.

Pitt, J. C. 2000. *Thinking About Technology*, originally published by Seven Bridges Press, New York, now: http://www.phil.vt.edu/HTML/people/pittjoseph.htm