PRAGMATISM AT WAR

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Seen from the redoubt of the physical sciences, one long war shadowed the last century from 1939 to 1989, and the story did not end there. Surveillance, communication, targeting, computation, and nuclear weapons have shaped much of the contours of science at the century's close. Engagement with the battlefield, with engineers, with a hidden enemy, conditioned the way physicists plied their craft—and the ways in which physics linked to the panoply of sciences around it. Confronting war, the pragmatist imagination in science took a specific turn.

At the largest scale, the war made the laboratory into a factory. After all, Los Alamos, Oak Ridge, and Hanford were not "like" factories, they *were* factories—factories that, in the case of Hanford, took over 130,000 workers to complete. Nuclear physics went from being an infinitesimal enterprise in early 1942 to an industry larger, by the summer of 1945, than the entire Detroit automobile manufactory. But the transformation was not just one of scale. Suddenly physicists had to speak with engineers, and perhaps more importantly they had to listen to the engineers' own way of parsing the world. Before the war, electrical engineering circulated around power production on one side and radio engineering on the other. By and large, physicists did not have much to do with either, although the material culture of radio engineering populated some laboratories. After the Japanese attack at Pearl Harbor, American efforts in radar multiplied explosively. For the first time, American physicists had to work side by side with radio engineers, and not merely by engaging the engineers as technicians.

On the contrary: To build new kinds of small-wavelength (and therefore accurate) radars, new tools were needed as the ordinary components of radio making were clearly irrelevant. Wires, capacitors, resistors, and inductors were not much different in length from the waves that made radar work. Consequently, the old-style radio components were useless: they simply became antennae. A new generation of electronic components that could move and modify radar waves into a useful searchlight would have to be designed out of copper boxes, slits, cylinders, and other hollowed-out conductive materials. Radio engineers therefore needed physicists. In particular, they needed theoretical means of tackling the complicated wave guides that split, transported, and transformed microwave radiation.

At first physicists took the view that they would simply "solve" the problem fully. After all, they were rightly proud that decades of experience with Maxwell's theory of electricity and magnetism had taught them so much about properties of electric and magnetic fields. But these peculiarly shaped devices of welded copper were vastly more complex than any previous problem in ordinary electrodynamics. Worse, the whole point of the radar work was to vary the circuits in an endless quest to improve performance, augment power, reduce the size of the waves, screen out noise. So even if one such complicated volume of copper could be understood today, tomorrow there would be two different ones on the engineers' table.

Wartime radar engineers desperately needed a microwave analogue of the kind of analysis they did for ordinary radios. For example, radio engineers did not calculate the detailed oscillations of the cardboard that vibrates in a loudspeaker. Instead, they characterized the speaker by a black box, that is, by an "equivalent circuit" that had the same relations of input and output as one found in a real speaker. The slogan was: give me the voltage in and the voltage out; give me the current in and the current out — I don't care what happens between the two points.

LEARNING TO SPEAK AND THINK LIKE THESE OPERATIONS-ORIENTED ENGINEERS BECAME A CENTRAL CONCERN OF THE RADAR PHYSICISTS.

On both the Japanese side and the American side, theorists, slowly and painfully, learned to abandon their older ideals of knowing the electrical and magnetic fields all the way down, so to speak. On both sides, facing each other across the battlefield, they learned to ask first and foremost after inputs and outputs, shunting aside the search for the detailed processes in the recesses of those copper volumes.

After the war, both Julian Schwinger and Shin'ichiro Tomanaga took their new-found black boxism to the heart of theoretical physics. Both began to abandon the search to understand what happened in particle collisions "all the way down," and instead both concentrated on characterizing the particles some distance away from their interaction. Particle physics, "pure physics," was reread as if it were a junction box in a radar circuit.

We are now quite habituated to thinking of theory, whether in philosophy or physics, as trickling down to the other domains of knowledge: it is yesterday's news that physical theory might shape experiment, and experiment might lead to changes in engineering. By contrast, it inverts our prejudices to see pure theory rewritten because of its encounters with the works of engineers. But it is this latter, engineering-driven process that so characterized the wartime engagement of the sciences. Month after month, year after year, wartime physicists and engineers attacked problems in this bottom-up way, with physicists always pressed to confront the problem of rapidly scaling up to production long before "normal" prewar procedures would have let it be so.

It is well known, for example, that Richard Feynman spent the war at Los Alamos. We usually hear his often-told anecdotes about cracking safes, outwitting psychiatrists, and playing bongo drums — an interruption from physics. But what Feynman actually did at Los Alamos is quite a bit more significant for the wartime history of the bomb, and also for what he did afterward. For example, Feynman was sent to Oak Ridge to inspect the facility's handling of the nuclear waste generated as the fissionable isotope of uranium, U235, was separated from the inert variety, U238. The Oak Ridge engineers knew perfectly well how many kilograms of U235 it took to create a fission chain reaction, so they separated the quantities of waste into separate barrels of U235, each of which sat in a solution that included water and contained less than the estimated critical mass. Feynman practically went into shock when he discovered that the water, by slowing down the neutrons and therefore making them more potent activators of fission, so dramatically dropped the critical mass that the Oak Ridge containers were on the ragged edge of having its waste matter go critical. Over the next months the engineers pressured Feynman to begin teaching them rules—rules to calculate the critical mass for different solutions, different concentrations, different geometries of storage. And Feynman produced these rules, rules of calculation useable by engineers outside the club of nuclear physicists.

Another example: on arrival at Los Alamos, one of Feynman's tasks was to calculate the amount of "active material" needed for various geometries of nuclear reactors. Again, after solving one geometry and then another, he began to search for a more modularized way of approaching the problem. Yet again Feynman faced this sort of problem as Hans Bethe, head of the theory group, assigned him the task of exploring various geometries that might be used as shapes for the atomic bomb's nuclear core. Here too engineers were never interested in just one configuration. They always wanted to be able to move one item, expand another, substitute a third: waste barrels, critical cores, reactor geometries. Feynman, a leading scientist of Los Alamos, was also its best student, learning to think about physics from a perspective that was both pure and engineered at the same time. When Feynman came back to pure physics after the war, he, like so many others, returned with a new vision of what science should be like; in his specific case, the war inflected his old interests in quantum electrodynamics. Now, in the years immediately following the war, he produced a set of modular relations that snapped into place — rules that could be used even by non-experts as they came, with his eponymous diagrams, to calculate the likelihood of electrons and photons colliding in various ways.

SCHWINGER ONCE SAID THAT FEYNMAN, WITH THIS DIAGRAMMATIC REASONING, HAD BROUGHT QUANTUM ELECTRODYNAMICS TO THE MASSES.

It was no accident. Over the course of four years, Feynman had had to learn to bring nuclear physics to the engineers and officers who handled the vast production system of a technoscientific world at war.

Philosophy of science had to skip a beat to pick up the rhythm of this new form of scientific work. Philipp Frank, one of the leaders of the left wing of the Vienna Circle (along with Otto Neurath and Rudolf Carnap) recast his philosophical views after the war. As a refugee in the 1930s, he had begun to assimilate the American philosophical tradition, hoping to join Viennese logical positivism with an indigenous American pragmatism and operationalism. Now, in 1946, after spending at least part of the war working on the wartime uses of applied mathematics, he began, self-consciously, to go beyond the grand, semantically based unification program of the prewar era. In one programmatic text written just after the war, he wrote: "[A] vast field of research is opened up. 'Hybrid fields' like 'mathematical biophysics' or 'mathematical economics' are no longer isolated cells where some awkward professors may enjoy their strange fancies but by the application of logico-empirical and socio-psychological analysis these 'cross-connections' become the roots of new developments leading toward the integration of human knowledge and human behavior. These queer cross-connections become the avan[t]guard of the science of the future." Among the goals of these new unified sciences would be an analysis of the role of governmental intervention in science — and the merging of science and technique.

Frank's plea for this new model of science issued directly from the scientists' wartime experience. The Harvard psycho-acoustic laboratory and the electro-acoustic laboratory were but two such piecewise unified structures. But a walk around any of the principal American campuses in the postwar period revealed many more such laboratories, and Frank needed only look to his colleagues in the Harvard physics department to meet, over and over again, veterans of these efforts. So when the Rockefeller Foundation responded to Frank's request for some modest funding toward the unity of science, they reflected, in their internal report, that biophysics, biochemistry, psychophysiology, and social psychology were the "borderland fields" that "contributed new data" to the quest for a unitary picture of nature.

One of the fields of inquiry taken up by Frank's new Institute for the Unity of Science was cybernetics. A term coined by Norbert Wiener, cybernetics designated that collection of fields concerned with self-governing processes, that is, fields where feedback leads a system toward a goal. Wiener's own interest in such processes began very early in the war when he saw the aerial threat to Britain as a decisive moment in history. Determined to develop a better method for tracking, and therefore shooting down, German bombers, Wiener began building a device that could characterize statistically an individual pilot's behavior and then use that characterization to predict his future moves. Knowing the airplane's position even a few seconds in advance would be sufficient for anti-aircraft fire to reach the plane and destroy it.

In rapid succession, Wiener began to generalize. First, he began to see the self-correcting Anti-Aircraft Predictor as equivalent to the pilot's intention; the pilot was nothing other than a self-correcting device. Then Wiener and his colleagues came to apply the same form of analysis to the anti-aircraft gunner — the "we" and the "them" entered into a similar regime of calculation. But the spiral of expansion continued:

NOT JUST THE GUNNER AND BOMBER BUT THE GENERALIZED HUMAN TASK WERE FORMS OF GOAL-DIRECTED FEEDBACK SYSTEMS. SELF-GUIDED MISSILES AND TORPEDOES WERE REALLY NO DIFFERENT FROM THERMOSTATS AND HUMANS TRYING TO PICK UP A GLASS, OR A HEART ESTABLISHING AN APPROPRIATE BEAT.

Wiener would write in 1950: "We believe that men and other animals are like machines from the scientific standpoint because we believe that the only fruitful methods for the study of human and animal behavior are the methods applicable to the behavior of mechanical objects as well. Thus, our main reason for selecting the terms in question was to emphasize that, as objects of scientific enquiry, humans do not differ from machines."

Soon Wiener's cybernetic program became a rallying cry for computer scientists, economists, cultural anthropologists, physiologists. So effective and all-embracing did it seem that it made perfect sense for Wiener to begin speaking in theological terms: "Since I have insisted upon discussing creative activity under one heading, and in not parceling it out into separate pieces belonging to God, to man, and to the machine, I do not consider that I have taken more than an author's normal liberty in calling this book *God and Golem, Inc.*"

Certainly many of Wiener's social and natural science colleagues saw such a move as reasonable — Philipp Frank's Unity of Science organization took up religion as one of its interdisciplinary "borderland" areas, working it with the same postwar pragmatic enthusiasm as they did problems of linguistics, anthropology, and computation. Cybernetics itself became a major research arena for the Unity of Science movement. And yet, despite this globalizing impulse of the cyberneticians, the field of inquiry retained certain features of its wartime origins. Always Wiener returned to a vision of the world cast in terms of struggles against an Opponent — sometimes a manichean enemy, the opponent of games and war. This was the other faced down by operations research, game theory, and cybernetics — the three manichean sciences, as I've called them elsewhere. And sometimes the antagonist was passive, similar to the manichean one, but incapable of changing the rules in midcourse. Nature itself was such an "Augustinian devil," and the struggle for science was a battle against this opponent.

How different these local patches of common knowledge were from the esperanto-like dreams of prewar Vienna. Not only did religion shift from its prewar place as a "pseudo-problem" to a postwar topic of inquiry. Even more importantly,

ONE SEES HERE THE ABSOLUTE LIMITLESSNESS OF THE PRAGMATIC MODERNISM THAT EMERGED FROM THE WAR.

Here was a pragmatic vision that was more than a simple transcription of the pragmatism of Peirce, James, or Dewey. This new stance before the world was a different kind of pragmatist imagination, an engineering take on the knowledge that permanently altered its form.

As we examine the intersection of pragmatism with war, we must not halt the analysis at the level of images of the nuclear or imaginary projections of a demonic enemy. At stake were far more fibrous forms of reasoning that guided scientific inquiry in much more subtle and encompassing ways — the turn to black boxes, intensive calculation, simulation, modularization. Hanging over the whole: the seeming inevitability of understanding as antagonism, be it manichean or Augustinian.

Further development of the themes presented here on cybernetics, postwar scientific unification movements, and wartime physics can be found in some of my previous publications: "The Ontology of the Enemy: Norbert Wiener and the Cybernetic Vision," *Critical Inquiry* 21 (1994), pp. 228–66; "The Americanization of Unity," *Daedalus* 127 (1998), pp. 45–71; *Image and Logic: A Material Culture of Microphysics* (Chicago, 1997); and "Feynman's War: Modeling Weapons, Modeling Nature," *Studies in the History and Philosophy of Science* 29B (1998), pp. 391–434.