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Introduction by Nicholas Humphrey

My grandfather used to vex me by praising my brother for "thinking with his hands." Even as a small boy I knew that the default assumption was that a person thinks with his head and that the rest of his body could be considered relatively dumb. When Rodin's Thinker, for example, rested his bronze head on his bronze hand, it was obvious in which of these two bronze masses the bronze thinking was meant to be going on. Yet here was my grandfather complimenting my brother for doing his thinking the wrong way round.

The three papers in this section address the relationship between technology and a special kind of thinking: science. If theory can be considered head and technology hands, then these papers have in common their emphasis on how much of scientific thinking too is done with the hands. Indeed they make it clear how far-to a surprising degree-in the history of science the theorizing head has tended to be the pupil rather than the master of the working hands.

It has not always been so clear. The picture many of us inherited from an earlier phase in the philosophy of science was more one in which theory was always in the lead. Pure science took precedence over applied science. Theorists talked down to mere technicians. The best science was motivated by intellectual curiosity, and if practical applications potentially followed from it their development could and should be left to the backroom professionals. The theory of relativity, for example, had been for Einstein a work of purely abstract speculation, even if later an army of technicians would turn his insight into an atomic bomb. The discovery of the genetic code had been for Watson and Crick a thrilling exercise in reading a chemical cipher designed by evolution, even if later a whole industry of genetic engineering would be raised on it.

Yet it hardly needs saying now that this picture bore almost no resemblance to reality. For a start, as several papers in this volume show, the fact is that technological development has mostly occurred quite independently of science. Throughout most of human history, the invention of new tools and new techniques has owed little if anything to theory of any kind at all. Instead, in the fields we now call manufacture, agriculture, medicine, warfare, and so on,

people have usually solved the practical problems of how to get things done more by good luck than good theoretical management-relying on trial and error, guesswork, copying (and fortunate mistakes in copying), and the selective retention of improvements-without their understanding or even asking why the eventual solutions worked. Indeed, the modem pattern of theory-led technological invention, which now seems to many of us typical, began to emerge only around two hundred years ago.

But that picture of theory being ahead of practice was unrealistic in another way as well. For not only has the development of technology until recently depended hardly at all on scientific theory, in fact scientific theory has depended very heavily on innovations in technology. It may be true that when Faraday in 1840 was asked by Queen Victoria if she might see his laboratory at the Royal Institution, he asked his assistant to go and fetch it on a tea tray. But, if so, Faraday was just showing off. The reality is that he and most of his fellow scientists would have got nowhere at all without the increasingly sophisticated tools that technology provided for them. Again and again, new theoretical insights have in fact had to wait on the invention of new instruments of observation, measurement, and manipulation: better clocks, better lenses, better centrifuges, and so on.

Nor does the role of technology in science stop there. For theoretical insights have had to wait also on the invention of new tools of thought: and, as Peter Galison describes in the riveting paper that follows, these tools of thought may sometimes have been modeled on tools of practice. Everyone knows how Watson and Crick relied for their theoretical breakthrough on the newly available X-ray diffraction photographs of DNA; but not everyone knows how Einstein may have relied for some of his key ideas about relativity on images that were put into his head by his experience as a patents' clerk reviewing applications for new gadgets and practical inventions.

Still, it would be a mistake to swing too far the other way, and to replace the old picture of theory dominating practice with an exaggeratedly post-modern picture of practice dominating theory. In reality, the relationship is complex and reciprocal with the emphasis shifting one way, then the other.

I am reminded of the renewed debate in academic psychology about how best to describe the

relationship between body and mind. For most of psychology's history, the accepted picture has been the rationalist one, originating with Plato and urged further by Descartes, of there being two separate entities, body and mind. All higher intellectual faculties were assumed to belong to the queenly mind, and the body was relegated to the status of a lumpish hand-maiden. But there is now a revolution under way. As psychologists get closer to appreciating how minds and bodies really interact, they are being forced to recognize how far the body itself participates in the very processes of decision-making and intelligence that were formerly considered exclusively mental. Indeed, they are coming to see not only that the idea of a disembodied mind no longer makes theoretical sense, but that the body itself must be considered an integral part of the mind: being wise, intelligent, and even knowledgeable in its own right.

We all, it seems, think with our hands besides doing it with our heads and both together. As the three papers in this section illustrate, we do science the same way. Maybe the deep reason for this common pattern is precisely that human thinking has a fractal structure, with the same pattern of interaction between head and hands emerging at every level-cultural as well as individual-at which we engage the world.