The Differences Between Engineering and Science

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Technology has recently made a strong return to the political agenda. Some of us may remember former British Prime Minister Harold Wilson's 1963 speech containing the immortal phrase "The Britain that is going to be forged in the white heat of this [technological] revolution...". It is, perhaps, difficult to reconstruct the thinking behind the idea after so much time has elapsed. What seems plausible is that it was urging the nation to make the most of its strong scientific traditions to forge practical innovations that would give Britain renewed economic supremacy. As such, the idea dates at least back to Francis Bacon (Lord Verulam)—-that scientific research leads to a (profitable) innovation, with "profitable" originally (by Bacon) cast in terms such as "the relief of man's estate", and latterly meaning monetary surpluses that help to reduce national indebtedness. Bacon's message was at the core of Vannevar Bush's rather influential 1945 report "Science – The Endless Frontier". Following this tradition, the present UK government has recently issued reports such as "Ingenious Britain" (2010), which squarely states that "industry, science and technology create jobs and create wealth" and "Innovation and Research Strategy for Growth" (2011), which bluntly urges that "the UK must strengthen its ability to accelerate the commercialisation of emerging technologies". The latter report makes a clear distinction between academic science, which is considered to be very strong in the UK, and developing new (emerging) technologies, which is considered to require strong pushing by government and, furthermore, introduces a third category, innovation, defined as "the development of new products, services and processes".

Dame Kathleen Lonsdale has defined science as "knowledge obtained by observation, by experiment and by subsequent deduction ... the object of the scientist is the determination of general laws and the deduction of principles from the effects which are observed". While this sounds plausible, it suffers from the same defect as the Bacon/Bush message: lack of empirical support. As Thomas Kuhn has pointed out, the very few known examples of this putative process of deduction from observed effects "shows just how improbable quantitative discovery by quantitative measurement is." Technology, on the other hand, is defined in the dictionary as "the science of the industrial arts", from which it follows that a technologist applies scientific principles and imagination to the creation of useful products required by society.

Engineering may safely be taken as a synonym for technology. In his book "The Social Function of Science", J.D. Bernal describes the ideal organization of science and engineering in society: Any problem with which society is confronted can either be solved by applying known fundamental principles, or be reduced to a form involving fundamental questions, which then need to be investigated. This description would cover a great deal of the human activity commonly called "research". It also gives a natural sense to the terms "applied science" and "basic (or pure or fundamental) science". It would be mistaken to suppose that the description is all-inclusive, however. Some fundamental science is carried out in any case, without being motivated by some unsolved practical problem (Bacon also recognised this as a valid reason for doing science), and it is also the business of people to ascertain how new fundamental knowledge generated without a practical motivation can be harnessed for a useful purposes, in industry or medicine for example — whether the discoverers of the new knowledge or those who see business opportunities in exploiting the idea have the responsibility to take the initiative in this is still vigorously debated, especially in the technology transfer community. One should also be mindful of the fact that, in reality, very few problems can clearly be assigned to the "applied" or "basic" categories. The late A.M. Prokhorov was insistent that there is no categorical distinction between the two; rather, they form a continuum and the intellectual challenges may be as great at one particular point in the spectrum as anywhere else within it.

The vision espoused by Bernal, which admittedly seems sensible and appealing, is that important problems emerge from some kind of social consensus (e.g., the United Nations "Millennium Goals"). A more specific example would be the development of suitable materials for constructing the space elevator. The problem is then analysed using known knowledge and if gaps are revealed the scientist sets to work to fill them. In reality, however, we know that this rarely happens spontaneously. Science has its independent mission to uncover hidden truths about nature and the scientists are guided by their intuition about what is important to investigate, which may only be slightly influenced by practical human needs. On the other hand, the engineer, when confronted by problems, for which existing knowledge is inadequate, will not wait for the scientist but will forge ahead, using heuristic methods to establish a bridgehead in unknown territory, achieving what the scientists may have deemed to be "impossible" — one recalls Lord Kelvin's verdict on heavier-than-air flying machines.

Not too dissimilar from Bernal's vision of the rational organisation of the problem-solving is Philip Sporn's definition of science as "an evolving body of systematic, experimentally verifiable knowledge regarding the relationships among the complex phenomena of the physical world", while the engineer "utilising the knowledge made available by the scientist, develops the means for controlling man's physical environment and transforming the conditions of life." I would again emphasise that the engineer himself expands knowledge as necessary when what he needs has not been made available by the scientist; the development of those means may require research just as intensive as that of the scientist in his explorations.

The corollary of this is that, as Sporn has pointed out, the engineer has a far wider mission, embracing all of human experience, than the scientist. We see this in the life of I.K. Brunel, and read it in his immortal words "I am now Engineer to the finest work in Britain" (after he was appointed to the Great Western Railway). This is "relieving man's estate" with a vengeance — and it is worth recalling that the early Royal Society was more like a society of engineers than of scientists, fostering a strong practical interest (the word "scientist" was anyway only coined about 200 years later), and even a definite bias against inductive hypothesising (cf. Lonsdale's notion), which we would nevertheless now recognise as constituting the very heart of science.

Thus the scientist has an easier task – he or she is only dealing with the absolute arbiter of nature; hypotheses are to be tested by experiments according to openly revealed procedures, hence even if an individual investigator's experiments are biased through being guided by hypothesis, other scientists can carry out their own, different, experiments, and the collective effort may be reasonably impartial (here the insidiously deleterious effect of the committee on scientific progress can be mentioned: if the allocation of resources to scientists is decided by committee, as it mostly is nowadays within the framework of research councils, science foundations and the like, the mainstream will by definition always be in the majority, and sufficiently different investigations might not be approved, hence impartiality is unlikely to be achieved). On the other hand, the engineer is forcing changes ("transforming the conditions of life") that cannot be absolutely justified in any way. Even Brunel's enthusiasm for railways was not shared by all his compatriots: Ruskin, for example, was an eloquent opponent. Sporn (an electrical engineer) proudly remarks that the engineer brings into being a major product or system, *vital or necessary* in human society, in a fashion more economically and more efficiently than has been accomplished heretofore. This grand vision of course requires much greater breadth than the scientist needs for his work. Turning again to Sporn, in his elements of an engineering philosophy he includes: (1) a sense of social responsibility; (2) the ability to bring resources together (including the garnering of public support for engineering projects); (3) mastery of the principle of economy of resources (nowadays we would call this "sustainability"); and (4) the ability to integrate scientific knowledge and where that is absent to interpolate or extrapolate experience (i.e., engineering empiricism). From this it follows that there is a strong ethical, hence ultimately arbitrary, dimension to the work of the engineer. For who is to decide what is vital or necessary in human society? Is there really such a thing as a social consensus, vague and impalpable perhaps, but which nevertheless results in a distinct dynamism in a particular direction? Or is it a matter of unshakeable personal conviction? The scientist is confronted by no such dilemma. All that is required of him is unimpeachable integrity, which the physicist Richard Feynman has summarized as "to try to give *all* of the information to help others to judge the value of your contribution; not just the information that leads to judgment in one particular direction or another". Thus, for example, if one has proposed a new theory, one must give all the facts that disagree with it, as well as those that do agree with it. The engineer cannot work in this fashion. For example, were Brunel to have acknowledged the arguments of the London & Southampton Railway Company, the Great Western Bill might never have been passed. In this sense, the engineer has more in common with the lawyer than with the scientist: facts and opinions must be marshalled in order to achieve a desired result; engineering is definitely not just "applied science". Sometimes, the neglect of certain facts necessary to promote the cause leads to disaster – as in the case of the first Tay Bridge. Presumably that is why there is pressure to have regulators for some engineering systems – although that development was firmly rejected by Brunel, who pointed out that the engineer has both more ability and more motivation to look after public safety than the regulator.

As the scale of engineering activities expanded, vast systems, of which the railways were perhaps the first example, were developed; others include telecommunications and water and electrical power supply and distribution networks. Engineering itself developed a specific branch, systems engineering, to encompass these, but many contemporary systems, without which society as we know it could scarcely function, are barely concerned with traditional engineering. The most prominent examples are health, education and food production. While Sporn's engineering philosophy does not in principle exclude such systems, the specialist knowledge (medicine, perhaps even molecular biology and pedagogics) required is really too far from the engineering disciplines to enable the engineer to tackle them with confidence; thus there is a strong drive for expertise even more all-encompassing, the possessor of which might simply be called a "systems professional".

The concept of social responsibility was strong in the minds of the early Victorian engineers such as Brunel. Unfortunately, it later became distorted. As A. Weir already pointed out in 1886, "beneficial undertakings had been proved profitable; [later] it was assumed that a business, as long as it is profitable, does not require to be proved beneficial". There has undoubtedly been a tendency for profitability to become the sole criterion of vital necessity. Thus, for example, it is not really examined in any deep sense whether we need more roads; it suffices that roads and motor cars appear to be profitable (although profitability, as any accountant knows, is just an artifice that can very easily be manipulated). For decades railways were neglected, even by engineers, because they were, apparently, unprofitable, despite their quite indisputable engineering advantages with respect to safety and sustainability. Actually, it is the scientist who has the habit of examining things in depth, hence it would be desirable if a convergence of science and engineering accompanied the rise of the systems professional.

In this light, the recent report of the UK House of Lords "The role and functions of departmental Chief Scientific Advisers", concluding that the role should be strengthened, seems peculiarly passé. Even in the recent past, a Chief *Engineering* Adviser would have seemed more appropriate to appraise many of the grand schemes under consideration (such as the use of wind turbines for electricity generation), since all the elements of Sporn's engineering philosophy, of which science is just a part, are required to provide an adequate judgement. The report actually obscures the difference between engineering and science (the scientific adviser is expected to give engineering advice as well); as we have seen above, the two are fundamentally different in outlook and combining them in one post is not credible. Actually, recent experience with Government Chief Scientific Advisers (some of whom have, actually, been engineers) has shown that they have a tendency to adopt rather dogmatic positions on important public issues, far removed from Feynman's ideals of integrity. What is really needed is a *Chief Systems Adviser*, who would hopefully have the humility to see his or her role as being one of *primus inter pares* with national interests taking precedence over personal ambition.

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