The 'making' of the mind of an engineer — Some thoughts on engineering education in India

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The academic training an engineer receives in her education sets the initial conditions for her contributions as an engineer. The successes and failures of our engineering sector are therefore traceable, in some measure, to the education system that prepares our engineers. This is not to deny the importance of life and experience in what an engineer delivers in her profession; it is rather that, if education is completely irrelevant, there is a problem right there that needs to be addressed. After seven decades of independence, it is therefore pertinent to look at how our engineering education system has evolved and how it has delivered.

In 1947 when India looked with hope towards her future as a free country, an immediate problem she had to grapple with was that of a severe shortage of skilled engineering manpower needed to address the gargantuan developmental challenges that lay ahead. Faced thus with the urgent task of developing the manpower needed, the leadership of the day opted to adopt the western model of engineering education for our country. In this article, we take a look at the way the system has evolved over the years, how it has performed and attempt to analyse what, if anything, is missing in the discourses that shape engineering education in the country. For present purposes, we use the terms 'engineering' and 'technology' interchangeably, as referring to the same general body of activity.

1 A little history

Let us pause to take a look at the sort of technological world that India stepped into, when she became independent. The twentieth century was characterized by an unprecedented development in science and technology, with its epistemic centre in the west. Engineering achievements in communications, transport, healthcare and other areas completely transformed the lives of people and communities. This, and the resultant growth of the big corporates, led to an ascendancy in the prestige of engineering and management education. The land grant universities had already come into being in the US in the previous century, but the focus of education changed from imparting practical skills to imparting the fundamental principles of science and mathematics. The Society for Promotion of Engineering Education (SPEE) had been formed in 1893 to oversee this change in the US [1].

The second world war saw an increasing emphasis being brought on research in the University scene. This saw, in the US, the SPEE being transformed to the American Society for Engineering Education (ASEE), a society which played an important role in shaping curricular changes. The war also brought into sharp focus the destructive potential of technology, and led to a certain amount of disillusionment with technology. Above all, it led to the recognition of a need for a 'character-building' component as an essential part of engineering education. Subsequent events through the 1960's, connected with the Vietnam war and consequent general social unrest on campuses, forced the emphasis back from research to teaching in the US to an extent [1]. Thus, in addition to the discourses on science and commerce, a democratic discourse was starting to play a role in engineering education. Another consequence of this was the initiation of several affirmative action programs in the Universities, aimed at recruiting women and minorities into engineering.

If a phenomenal growth of technology (and its use for good and bad) was one distinguishing characteristic of the previous century, another was a sharp discontinuity in the political order in the world. Post-war decolonization and the drain of the two wars saw a decline in the power of Europe and the rise of America. Many countries obtained political independence after the Second World War, resulting in a complete redistribution of political, economic and social power in these countries. While developments in science and technology and development of engineering manpower went hand in hand in the western countries, this was not so in the newly independent countries, in which a continuity in local technological traditions had often not been maintained. Not surprisingly, countries like India opted for the western model of education.

This then, was the world scene at the time of India's independence. Having set herself a target of becoming an Industrial economy and with 36 Institutions in the country offering a first degree in engineering with an annual intake of about 2500, the task to build up the educational infrastructure was urgent. Thus forced by need and propelled by aspirations, India undertook a massive expansion of engineering education in the following years. The Indian Institutes of Technology (IITs) were created by an Act of parliament. In the second plan period (1956-61) four of the original 5 IITs (IIT Kharagpur was already functioning by then) and 11 of the 17 Regional Engineering Colleges (RECs) were established [2]. Simultaneously, several new engineering colleges were also started, and the existing ones significantly expanded. In contrast to the Institutions existing at the time of independence which had a fairly static curriculum which emphasized practical aspects of engineering over principles, the IITs were envisaged to have a dynamic, science-based curriculum. The five IITs gradually took on a character inspired by the American model of Land Grant Universities where research is considered to be as important as teaching. The growth of the research culture was further fueled by the creation of Government Departments such as DRDO, DST and DOE in the 1970s. On the Industrial front, the vision was to spur the development of home-grown, science-based technologies - the CSIR had come into existence for this purpose even before independence. On the whole however, the development in this direction was slow, and opportunities for the graduates of the IITs seem to have been less than challenging.

The general emphasis of the early curricula was on basic and engineering sciences, with a significant content of Humanities and Social Sciences. The 'professional' content of the individual engineering disciplines was limited to 30-35%. However, subsequent developments saw a progressive dilution of this philosophy, with the professional content increasing at the expense of basic sciences, engineering and humanities (see [2] for an interesting account of the evolution of the curriculum at IIT Kanpur). A partial compensation was sought to be provided by increasing the flexibility in the curriculum, but the net result has still been a dilution, especially of the humanities component. There has also been a gradual erosion of those components of the curriculum which sought to bring the student close to engineering practice, such as industrial internship. Other changes have been forced by developments in computerization and the rise of new specialized disciplines.

2 Performance of the system over the past decades

We may measure the performance of the system against the yardstick of what the society generally expects out of its educational system. These expectations can be grouped under the following heads:

- **Manpower training:** Creation of trained manpower —
  - —for the government and private domains to boost the productivity of the Industrial and agricultural sectors,
  - —to provide directions to harness science and technology in a responsible manner for the public good,
  - —to provide policy directions so that India may set and work towards its developmental goals, and also offer original thoughts on global issues.

- **Research:** Provide thought leadership and enrich the global 'knowledge pool'; also create adequately skilled research manpower for the Industrial and governmental R&D sector.

- **Development:** Provide —
  - —technological solutions to the country's problems so that the fruits of development reach all sections of the society,
  - — goods and services that enhance the quality of life of all sections of society.

Considered against these expectations, it must be admitted that significant achievements have been made. IITs have become known worldwide for the quality of their graduates, there have been important contributions to the published and patent literature in engineering disciplines, there have been important additions to national infrastructure. All these have contributed to an increase in the quality of life for a large section of the population. The INAE has recently brought out a compendium on Indian engineering achievements [3]. That said, it must also be admitted, if one takes a dispassionate view, that there seems to be a disconnect between the achievements and the goal of building a technological society that is just, fair and equitable, and at the same time forward looking and a role model to the global community of nations. While the education system has been churning out its graduates, the country's development has been uneven, with the fruits of technology largely going to the urban sector. This has led to a migration from rural to urban areas, resulting in a whole new set of challenges for the urban sector, and a progressive worsening of the rural situation in several states. Large unanswered questions remain on the manner of utilization of national resources, and the way in which developmental goals are set. In research too, it has been said that the problems being addressed in our institutions of higher learning are those made fashionable in the west; the Indian elite institutions have not, in general, been seen as a fountainhead of new ideas or new technologies. On the manpower training side, IITs were expected to act as role models for the rest of the engineering institutions in the country, but the gap between the first tier colleges and the rest has, arguably, only widened over time. The result is that, while there has been considerable expansion in the number of graduates coming out of various engineering colleges in the country, much of this number is generally seen to be of too poor a quality to attract the attention of employers. There also seems to be a disconnect in general, between the training a student goes through in the engineering college and the kind of vocation she pursues after graduation. Clearly, there are problems of considerable magnitude crying out to be addressed.

3 Reasons for the expectation-achievement gap: An analysis

The disconnect mentioned above between the broad goals of nation building and the achievements of the engineering sector points to a problem of awareness: does our training of engineering professionals make them sufficiently aware of the nature of their activity, its place in society, and the socio-cultural milieu in which that activity would be taking place? These questions are more relevant to engineering training than to scientific training - while the answers science seeks are of a universal character, engineering solutions, though technical and maybe based on universal scientific principles, have a social, political and cultural context to them. Staudenmaier [4] argues that different cultures develop different 'technological styles'. Viewed from this perspective, the problem may be traced back to the discourses that have defined and shaped engineering education in our country. Sadly, a deep analysis of this issue has been missing so far, the easier route of uncritically following the best practices evolved in the west being usually taken.

An examination of the situation reveals that the discourses which have held sway through the evolution of the engineering education in the country have traditionally been those of science and commerce. The situation is not unique to India [5], but probably has stronger implications for a young country like ours with aspirations of leapfrogging across the developmental divide. Good engineering, in the end, is more than about application of science (since the same principles can be built into a multitude of technological solutions, some relevant and others less so to the context of application), and more than about creation of wealth (since questions of equitable development, environmental concerns, societal concerns have to be factored in). This implies that the engineer should be made aware, as a part of her academic training, of the other discourses at the intersection of which her activity stands. These other discourses that may be mentioned are those of engineering itself, philosophy, history and democracy.

3.1 The engineering-philosophy discourse

We consider these together because a number of issues are common to the two threads; further, the nature of engineering is, after all, a question in philosophy. It is a thesis of this essay that philosophers in India have not become engaged adequately with this question. Indeed, philosophy of technology is a relatively new discipline even on the world scene [6].

The question we want to address from a philosophical standpoint is whether engineering deserves its own place in the sun apart from that of science. Let us first note, with this purpose in mind, that it is really not necessary to distinguish between 'science' and 'engineering science'; the whole thing is really a continuum.

What is the nature of engineering? Is it technical art, is it applied science? Views have tended to swing between these two extremes. The former view emphasizes the creative aspects of technology, and hence attempts to trace a continuity with art. This view gained prominence at the time of the Renaissance in Europe, but the proponents of the view tended to be from backgrounds other than science and engineering, and therefore had little first-hand experience with the methods of either. Technology may have come about initially as an expression of man's creativity being employed towards a better lifestyle, but over the millennia, science has caught up to a stage where it is itself spawning technologies. Further, technology has become indispensable to the progress of science as demonstrated by the need for sophisticated instrumentation and computing devices, not to mention gigantic artefacts such as the Large Hadron Collider. This symbiotic existence of science and technology in the modern day, makes it difficult to draw a clear separation between the two, but more importantly for our purposes, it diverts attention from other aspects of the personality of technological activity, than the purely scientific. While the heavy scientific underpinning of technological action (see Mario bunge [6]) cannot be denied, the type of superstructure technology builds has to be sensitive to multifarious other factors, as already pointed out. The view has been put forth by Skolimowski and others [6] that science is about what is, while technology is about what should be; in other words, science concerns itself with the world as it is, while engineering tries to change it to better suit our purposes. This then brings up the question of who decides what is to be. If it is accepted that this decision is itself external to technology, it leads to the view that technology is value-neutral, a view that may not be entirely correct (besides having undesirable connotations on the responsible use of technology) considering that many technologists are self-motivated in their work.

One has to thus accept a working definition of technology in order to make progress, while the philosophical questions continue to be debated. Following Vincenti [7], we may think of engineering as being concerned with the design, production and operation of artefacts which change the world around us in some premeditated way, in order to achieve some recognized need. The centrality of design in the activity of an engineer has often been emphasized [6,7]. Vincenti[7] describes the hierarchical structure of the design activity, and shows how the upper strata of the activity (which are concerned with the conception of the problem and its formulation in engineering language) are subject to contextual influences from other fields such as sociology and environment, while the lower strata (concerned with the production of plans, prototypes, etc) depend on 'engineering knowledge' that derives from a complex interplay of experiment and theory. This latter thus employs methods similar to science, but is a body of knowledge that stands on its own.

From the viewpoint of epistemology, recognizing that the body of engineering knowledge is something that stands apart from, and converses with, the body of scientific knowledge, has important implications not brought out by the simplistic view that engineering knowledge is a part of scientific knowledge. Recognizing this and according to engineering knowledge its rightful place is essential to the growth of that knowledge, and for preparing the ground for original contributions in engineering.

The relevance of the above to the present analysis of engineering education are obvious. A view of engineering that emphasizes its individuality emerges as an essential component of engineering education. The lack of this is probably a main reason why there is a neglect of (one might even say a lack of respect for) purely engineering work in the academic sphere. Vincenti's account of airfoil research in the early decades of the last century is instructive on how important such research can be for progress. Similarly in the initial years of the biology revolution, enormous effort was spent on generating random mutations and screening the mutants for desirable traits, and much progress in industrial biotechnology resulted from such efforts. Of course, such purely empirical research does involve considerable investments, but history shows that such investment is worthwhile in creating a leadership position in technologies. It may even be argued that a similar order of importance and multiplication of effort is necessary for developing meaningful solutions to the problems that beset India's countryside.

3.2 The history-democracy discourse

As in the case of the previous discussion on engineering and philosophy, it pays to consider history and democracy together in this broad analysis. History is replete with instances of public pressure influencing the adoption or abandonment of technologies: developments in the tobacco industry, automotive fuel (lead and its replacements), Chlorofluorocarbons, are prominent examples. But there are also debates engendered by social (rather than human health) issues that have impacted technological developments - we in India are witnesses to several. Staudenmaier [4] recognizes three phases in the life of any successful technology - a design phase, a maintenance phase and a senile (or obsolescence) phase. The design phase, which we may call as the phase of ‘tooling up’, is characterized by flexibility - the technology is responsive to external inputs in this phase. In the maintenance phase, the technology has gained such momentum that the society tries to adopt itself to its ways - the technology itself is rigid in this phase. In the final phase, other competing technologies, themselves in the design phase, are trying to replace the old technology, but the rigidity developed in the maintenance phase tries to counter this. The point is illustrated by the history of the automotive industry in the US. Staudenmaier also categorizes the different stakeholders who play a role in the adoption (or continuance) of a technology in its various phases, among various constituencies. His illustrations are instructive of the kind of democratic pulls and pressures which are active at various stages in the life of a technology. It is particularly important to recognize the vested interests that come into being in the maintenance phase of the technology, supported advertently or inadvertently by governmental regulations and societal adaptations to the technology, which often militate against rational decision-making.

Since historical times, technology has inspired excitement and awe on the one hand, and fear on the other. Philosophical discussions on technology have tended to be of two kinds: the analytical tradition referred to in the earlier section is a late entrant in the field; the earlier tradition by far, is concerned with the effect of technology on society and is continuous with traditions in sociology and the humanities [6]. The kind of fear inspired by technology, that it has a Frankenstein-type potential to run on its own logic and take over its maker, is prevalent even today and is articulated in discussions of artificial intelligence, genetic engineering, and so on. The wealth of fiction and movies on such themes is also a testimony to the public imagination that the theme captures. Given such a scenario, views held by influential people or cliques, well informed or otherwise, have played an important role in history in advancing certain types of development over others. For example, the view, going back to Aristotle, that there is a fundamental difference between ’natural’ substances and human-engineered artefacts, and that technology can never reproduce ’natural’ substances, formed an important basis for the criticism of alchemy. Proceeding further, similar views also delayed the emergence of synthetic organic chemistry as a discipline. It is a consequence of the political developments of the twentieth century that public opinion is increasingly taking a position of influence in deciding on technological options.

In recognizing the role of democracy in technological decisions, one should emphasize the need for informed debates; engineers and technologists themselves have the role of spreading awareness about the pros and cons of different technological alternatives. While there is often an impatience about the time taken for decisions to emerge in a democratic set-up, if the delay is caused by informed debates, it is time well spent, since adoption of large scale technologies can completely alter the landscape of society for decades to come. A knowledge of democratic traditions and institutions, would therefore seem to be an essential component of the repertoire of an engineer.

4 Epilogue

In this essay, I have tried to take a step back and seek reasons for the gap between the performance of our educational sector and its engagement with national developmental goals, and identify the missing pieces in the thinking that informs engineering education in the country. A preoccupation with the 'disciplinary' content of engineering curricula, which has led to a total lack of an in-depth analysis of the different discourses that should inform engineering activity, is identified as the main reason for the gap, and for an uncritical adoption of western models to answer our educational needs. Clearly, such an analysis has to be an ongoing one which continuously interacts with the 'practice' of engineering education. It also calls for a continuous research effort and development of resource material in areas such as the philosophy of technology, history of technology and the nature and role of democratic institutions in the context of engineering activity. It is essential that such developments are rooted in the Indian context for them to make a significant difference to the preparedness of our graduates to address our engineering and developmental challenges. Perhaps there is an urgent need for an Institutional framework which, from a vantage point, takes a meta-level look at the contextuality of engineering activity and develops this 'confluence of discourses' to guide the development of engineering education in the country. Such an Institutional framework seems essential so that the output of the engineering education system is relevant to, and sensitive to, national needs, while at the same time being in step with international developments.

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