Engineering Education: Training to Produce Technicians or Scientists?

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Abstract

Engineering professionals may be classified into two categories, Scientists and Technicians, depending on certain behavioural characteristics. Although both may possess high IQ, the Scientist is able to harness his or her energies far more creatively than the Technician is. The Scientist is intrinsically motivated, seeks to discover the true nature of physical reality, possesses a holistic outlook, and deeply enjoys the work. On the contrary, the Technician is deficiency-motivated, lacks the spirit of scientific enquiry, has a relatively narrow outlook, and is content with putting into application what is already known. This paper attempts to explore the main ingredients (such as enquiry, enjoyment, creativity and integrity) that make up the Scientist's temperament, and suggests that engineering education in general suffers for want of Scientists as educators. Examples are drawn from the fields of structural engineering and architecture, but the inferences are generalised enough to be extended to other engineering professions.

1. Introduction

There are, admittedly, shortcomings when it comes to classifying people (professionals, in this case) into two watertight compartments. But there are advantages in this simplification, and in this instance the merits of binary logic outweigh the shortcomings. In this paper, professionals (engineers, architects, etc.) are classified into two simple categories: Technicians and Scientists (Zukav 1980). Technicians constitute the run-of-the-mill category, whereas Scientists constitute the category of professionals of exceptionally high quality. Technicians, of course, constitute the majority; Scientists are a relatively rarer species. The behavioural differences between these two categories are markedly pronounced, and an understanding of these differences is important in the field of education.

What makes a Scientist so different from a Technician? Why are Scientists so few in number? What can we do in engineering education to increase their number (assuming, of course, that it is desirable to do so!)? This paper attempts to provide some answers to these basic questions, with specific reference to two professions, viz., structural engineering and architecture. The author's background as a teacher and consultant in the area of structural engineering is responsible for this limited focus. However, the observations and inferences made here are generalised enough, to be meaningful to other professions.

2. Scientist versus Technician

The terms, 'Scientist' and 'Technician', are described rather lucidly by Zukav (1980), with reference to physicists, as follows:

"When most people say, 'Scientist', they mean 'Technician'. A Technician is a highly trained person whose job is to apply known techniques and principles. He deals with the known. A Scientist is a person who seeks to know the true nature of physical reality. He deals with the unknown. In short, Scientists discover, and Technicians apply."

This interesting description, aimed at categorising physicists, may well be extended to engineers, architects and other professionals. The argument that engineering is an 'applied' science is of no relevance here, because there is tremendous scope for creativity even in the application of an applied science. Creativity implies innovation, and innovation in engineering demands a scientific temperament. Unfortunately, most engineers and architects are found wanting in scientific

temperament. They are trained to do routine things, whose significance they neither realise nor question. They may be very intelligent, but their vision is narrow, and they fail to inject inspiration and enthusiasm in their work naturally. These are the Technicians. One can see them everywhere.

Scientists, on the other hand, are a relatively rare species, amongst engineers as well as architects. It is their basic nature not to take things for granted. They question, probe, discover and create. Their creativity may take physical form, or may be in the form of original concepts. They are driven by some peculiar intrinsic motivation, which injects a dynamic dimension to all their activities. Their range of vision is broad, generally transcending their fields of specialisation. They are able to discover, synthesise and manifest in their own lives, a harmony between Art and Science, and between theory and practice.

3. Architect-Engineer Interaction

3.1 Technician Level

Much is said and lamented about the mutual conflicts that engage architects and structural engineers during the course of their interaction. In the consultancy business, architects and engineers generally tend to view each other with suspicion, and, at times, with condescension. More often than not, this occurs when the engineers lack 'architectural sense', and when the architects lack 'engineering sense'. In the eyes of the Technician-engineer, the architect is a fanciful dreamer, who likes to build castles in the air, and is far removed from reality. The Technician-architect, on the other hand, views his counterpart as being grossly unimaginative, devoid of aesthetic sense, and prone to the use of defensive technical jargon when he fails to deliver the goods. The result of their interaction is a compromise (invariably, more in favour of the engineer than the architect), and is arrived at after much wrangling.

This architect-engineer conflict has been cogently expressed by the famous 'shell builder', Felix Candela, as follows (Faber 1960):

"The architect wants to maintain his preconceived ideas, but has no weapons to fight against the scientific arguments of the engineer. A dialogue is impossible between two people who speak different languages. The result of the struggle is generally the same: science prevails, and the final design has generally lost the eventual charm and fitness of detail dreamed by the architect."

3.2 Scientist Level

It is only the Scientist-engineer who can share the dream of the Scientist-architect, and so succeed in accomplishing it. Both are conscious and appreciative of the importance of teamwork and symbiotic activity. They are aware of the limitations in vision imposed by their respective areas of specialisation, and hence realise the complementary nature of their activities. Unlike the Technician-engineer, the Scientist-engineer is inwardly grateful to the architect for the challenges posed by him. The challenge is viewed not as a threat, but as a welcome opportunity. Similarly, unlike the Technician-architect, the Scientist-architect looks forward to his interaction with the engineer as a means towards improving his design. Such an architect has a relatively open mind, realises the significance of structure in architecture (Salvadori 1986), and seeks to capitalise on the creative skills of his counterpart. Indeed, many an architectural masterpiece is also a structural one; the structure is one with the architecture.

In short, architects and engineers may seem to be poles apart, but fundamentally, they have much in common in terms of their basic mentality. They are either Technicians or Scientists, and Technicians and Scientists are the ones who can be said to be poles apart!

4. Mediocrity in Technical Education

What makes an architect or an engineer? A technical qualification in the form of a degree certificate. It is tacitly assumed that the four or five years of academic experience in a technical institute do the needful in preparing a student in architecture and engineering. The underlying assumption is that passing examinations in various subjects is an adequate measure of one's professional competence.

Hence, success in examinations is viewed as a necessary and sufficient condition for recruitment to various positions, particularly in the Government service.

The examination system, therefore, assumes awesome importance in society as a whole, particularly in today's highly competitive 'rat race' set-up. Students, teachers, parents, the Government - all are apparently overpowered and brainwashed by its import. Hence, it is but natural that the process of learning and teaching in many educational institutions becomes geared mainly towards exam-oriented instruction.

The ensuing result is a vast and overwhelming ocean of mediocrity - mediocrity in instruction, mediocrity in research, mediocrity in planning and design, and mediocrity in execution. The emphasis is on quantity, not quality; on Technicians, not Scientists. This problem is particularly severe in developing countries, which are struggling to keep abreast of the more developed nations.

The problem gets magnified over the years by the rapidly increasing 'information explosion', which results in an overloading of the curriculum to accommodate more and more information. As the pressure on the student builds up, survival demands that he be more selective and more exam-oriented in his learning, in order to beat the system. The student thus ends up becoming more mediocre. It's a vicious circle!

Nevertheless, there are exceptional individuals, who, by virtue of their intrinsic nature, do not fall into the rut of mediocrity. These are the budding Scientists, who are able to transcend the pitfalls of the socio-educational system. But the vast majority of students not only lack the qualities to react positively against mediocrity, but are, in fact, quite content to swim with the current. These are the Technicians - a self-propagating species.

Technicians have their place in any profession, no doubt. But it does not speak well of the health of any profession, if Technicians masquerade as Scientists and occupy key positions for which they basically lack competence. This is unfortunately the situation in many organisations, especially the ones in the public sector. Most thinking people cannot help but be conscious of this problem; but only a few of them are sensitive enough to do something about it in their own organisations.

Scientists alone are capable of perpetuating their unique culture. Under their inspiring influence, even Technicians undergo some transformation and are able to awaken and discover 'Scientist' faculties that lie latent in them. Every Scientist, therefore, is a born teacher. His teaching may not be deliberate; it operates as an invisible, but powerful, influence.

The scientific temperament is potentially latent in every intelligent individual, and can be awakened in a conducive environment. It is evidently the function of the educational system to provide and nurture such an environment; but this is sadly lacking in most educational institutions, which inadvertently encourage mediocrity. Unless otherwise inspired, the student is bound to be cast in the Technician mould, and to transmit this conditioning to his profession and to the environment.

To achieve excellence in technical education, and to avoid mediocrity, we obviously need Scientists as teachers. The so-called 'teacher-training' programmes operate under the assumption that existing Technician-teachers can be trained to improve their performance. Perhaps, they can; but not to such an extent as to transform themselves into Scientist-teachers. The scientific temperament needs to be awakened early in life; this cannot be done late in life.

5. Awakening the Scientific Temperament

The peculiarity of the scientific temperament is that it cannot be forcibly induced; it requires to be spontaneously activated. Hence, the verb 'awakening' is appropriate here, rather than 'cultivating' or 'attaining'. The individual must discover an aptitude for a profession that he has either consciously chosen, or which somehow has been thrust on him. Aptitude implies (i) a basic liking, plus (ii) an inherent ability. If either of these two components is missing, then the process of education becomes burdensome. If both components are missing, then it can be quite a torture! Faced with the latter situation, the sensible course of action would be to quit, and find an alternative occupation - ideally, for which one has a natural calling. As the Nobel Laureate, Isidor Rabi puts it: "It's too hard, and life

too short, to spend your time doing something because somebody else has said it's important. You must feel the thing yourself..."

The ability of students to score good grades, and their liking to do so, do not necessarily reflect good aptitude. Often, it is a mere reflection of their basic intelligence, coupled with a motivation driven by competition. Aptitude has nothing to do with competition; it must flourish even in the absence of competition, and will do so only if the student basically enjoys what he is doing.

Awakening the scientific temperament is all about (1) encouraging the spirit of enquiry, (2) transmitting enjoyment, (3) stimulating creativity, (4) enhancing sensitivity and intuition, (5) inspiring integrity, and (6) inspiring motivation. Let us examine each of these components in some detail.

5.1 Enquiry

Problem-solving and decision-making are the two basic skills required of any professional. However, these skills differ significantly, both in degree and kind, in Scientists and Technicians.

The Scientist's approach to a problem (any problem) is based on the question 'Why?', whereas the Technician's approach to the same problem is based on the question 'How?'. The Technician is concerned about how to solve the problem, whereas the Scientist is keen on understanding why it is a problem in the first place. To the Scientist, the problem is something interesting that needs to be addressed fundamentally (and often, immediately). To the Technician, the problem is something bothersome that needs to be got rid of (unless, perhaps, there is an economic consideration involved!).

In short, the spirit of scientific enquiry is lacking in the Technician. Hence, his solutions are bound to be second-hand and routine, devoid of originality and creative content. This approach is usually an outcome of a training (a bad habit, one might say) imbibed during the course of one's formal education. It becomes difficult to get rid of this conditioning and to be able to arouse the spirit of enquiry later in life.

Structural design, for example, is taught in engineering schools, with reference to codes (standards). However, the codes are not meant to be used as a substitute for basic understanding and engineering judgement. The student must learn to question codes - as indeed, he must, nearly everything in life! (Pillai and Menon 1998). Unfortunately, the Technician-designer falls prey to the all-too-common habit of blindly following codes. Similarly, blind application of conventional methods of analysis and blind use of software packages, without understanding their bases, can sometimes lead to error and catastrophe. The mere fact that a structure is standing (i.e., not yet collapsed) is not always a testimony of structural engineering skills. Indeed, many structures stand, not because of good engineering, but in spite of bad engineering.

Interestingly enough, every individual would have experienced the spirit of scientific enquiry during early childhood. How spontaneously children pose questions about things that they do not understand, but are eager to! With the passage of years, however, they become more and more restrained and inhibited in their questioning - partly because a positive response is not always forthcoming, and partly because of a growing sense of self-consciousness. The loss of the freedom to question psychologically conditions the student, represses his enquiry, blunts his intellect, and prevents the full and free blossoming of his personality.

Under this situation, what is the role of the teacher in awakening the student? Zukav (1980) gives us a wonderful example:

"A Master teaches essence. When the essence is perceived, he teaches what is necessary to expand the perception. The Master does not speak of gravity until the student stands in wonder at the flower petal falling to the ground. He does not speak of mathematics until the student says, 'There must be a way to express this more simply'. In short, the Master does not teach, but the student learns."

This ideal style of teaching may not be easily practicable in the present-day system of formal education, due to the severe constraints involved in conveying a large volume of information within a limited period to a large number of students. However, it is still within the teacher's capacity to kindle

interest in the student, and to de-condition his 'set' mind. For this, the teacher himself may have to pre-empt and pose questions, rather than wait for the stimulus to emerge from the students. Despite the constraints, the Scientist-teacher remains a Master, and functions in his own creative style. True, he may not succeed in covering fully the prescribed syllabus, but he may well succeed in uncovering it! He realises that the curriculum is essentially a vehicle to awaken the latent intellectual faculties in the student, and not an end in itself. The emphasis is on how to teach, not what to teach; on self-discovery, not spoon-feeding; and on long-term benefits, not short-term goals.

5.2 Enjoyment

The spirit of scientific enquiry is usually coupled with a sense of intense enjoyment. There is a joy in finding answers to one's questions, and more so, if this is achieved by dint of one's own effort.

There is another kind of joy associated, not with the process of learning, but with the process of doing - the so-called job satisfaction. Many people do experience such joy occasionally, if not periodically. Scientists, unlike Technicians, experience such joy so frequently, that it becomes a part of their nature. It is not the kind of joy that comes to us when we make money or when we achieve fame. It is a very private kind of joy that does not depend on others. But it is a joy that could possibly be transmitted to others, as happens when one encounters a Scientist-teacher. On the contrary, a Technician-teacher is one whose classes are likely to be dull and boring, precisely because he has failed to discover the joy in what he is teaching.

Is one able to enjoy the process of learning, the process of teaching, the process of working in one's profession for no ostensible reason - not for marks or money or status, but simply, for the sheer joy and beauty in it? There has to be something intrinsic in the profession to sustain one's interest and enjoyment; otherwise, one would easily tire of it. This suggests that there must be something new in it every time one looks at one's work. The discovery of 'newness', again and again, engenders creativity.

5.3 Creativity

Creativity is the most striking and illuminating characteristic of Scientists. Some psychologists define creativity as a product of fluency, flexibility and originality. Therefore, mere creation (such as the construction of structures) does not necessarily indicate creativity - especially if it is routine, unoriginal, or simply new for the sake of novelty. A creative solution must be appropriate and relevant to its context.

It appears that there is more scope and greater need for creativity in architecture than in structural engineering; but this is not necessarily so. It is perhaps more accurate to say that it is easier for an architect to express his creativity than it is for an engineer. The engineering profession, being so demanding in terms of safety and economy, tends to restrict avenues for innovation and experimentation. Technician-engineers find themselves so bound by codes and specifications that they use these as a pretext to rationalise their second-hand, stereotyped designs and construction practices. The Scientist-engineers, on the other hand, make their own rules and have their own unique ways of solving design problems, having well grasped the limitations and assumptions underlying accepted knowledge.

This probably explains why creative people are found to be highly intelligent. However, it is noteworthy that there are so many Technicians who possess high IQs, and yet lack creative imagination. Bound as they are by timidity, conventionality, anxiety and fear, they confine their energies to imitating, polishing, rearranging and generally tinkering around with what is already known. In contrast, Scientists are not only not threatened by the unknown, but they also relish its ambiguity, newness and mystery.

5.4 Sensitivity and Intuition

Sensitivity is a subtle and significant dimension of the mentality of the Scientist. It denotes a feeling of fine-tuning in a specific direction, leading to some kind of resonance. This resonance is usually accompanied by a feeling of wonder and joy. In the words of Einstein, "The most beautiful thing we can experience is the mysterious; it is the source of all art and science."

Scientists periodically experience this almost mystic feeling of wonder. Technicians, on the other hand, rarely have such experiences.

The 'aesthetic' sense is the most appropriate expression of sensitivity. Many people believe that this is an important requirement in architects. Clients often demand an 'exciting elevation' from the architect, without quite knowing what it means! The aesthetic sense does not relate to the visual beauty of some elements, but the beauty in the concept as a whole. It is derived from an experience of order and wholeness. Hence, even a simple mathematical equation can be the source of profound and delightful experience to one who is sensitive to its meaning. The Scientist makes a great and inspiring teacher if he is able to convey his insight to his students.

'Structural sense' is an expression of sensitivity familiar to Scientist-engineers. It establishes a direct experience of the load-transfer mechanism, and of the relative stability, strength and stiffness of the structure. It is an experience that usually precedes, and sometimes follows, mathematical calculations, and provides a necessary bridge between quantitative and qualitative knowledge. Technician-engineers mostly lack this 'feel' for structure, although they may have expertise in accurately analysing large and complex structures, and in calculating stresses and displacements to the nth degree of accuracy.

Sensitivity not only gives the satisfaction of perceiving the truth, but it also serves as a warning bell when something is seen out of place. The range of sensitivity may extend, in structural engineering, to areas such as sensitivity to detailing, sensitivity to economy, and sensitivity to ease in construction.

Sensitivity is the forerunner of intuition; only sensitive people can be intuitive. Intuition is a kind of sixth sense that immediately perceives the truth of things without reasoning and analysis. It has a peculiar strength to stand on its own, without the prop of accepted convention or bookish knowledge. No doubt, considerable sensitive experiences are required to enable the full awakening of intuition, which results from a synthesis of various sense perceptions.

The word 'intuition' has been much used in connection with Felix Candela. As Candela himself puts it (Faber 1960):

"It is always simple to explain the way you have done things after you have done them; but in many cases, such explanations are untrue, because one does not know exactly how one reached a certain point in one's thinking. When it comes to be explained, it can be seen clearly as a whole; the logical process is always an afterthought."

Intuition is too subtle and abstract a phenomenon to be communicated. Unlike sensitivity, it cannot be consciously awakened. However, one who has trained oneself regularly to be sensitive, is very likely to receive intuition.

5.5 Integrity

The scientific temperament of an individual is in many ways linked to his moral character. The Scientist is basically a truth-seeker. The importance of realising the truth, of getting to the bottom of things, is self-evident to him. Therefore, it is his basic nature not only to be intellectually honest, but also to reform and adapt in the light of the perceived truth. This implies mental alertness, sensitivity and perception to a degree well beyond the range of the unreflecting Technician mind. In later years, the Scientist's search for truth is likely to spill over to 'eternal questions', that are ordinarily described as ethical or philosophical.

The term 'integrity' is appropriate here, as we seek to describe a character of incorruptible quality and a vision that is holistic. Integrity is, admittedly, a scarce commodity in the present-day world. Corruption has infected society like a cancerous growth, and formal education has done little to check its damaging influence. Of course, sermonising on 'professional ethics' and 'professional commitment' is in vogue, but that has not really helped. There is often a hollowness in these terms, and one is reminded of the poetic words of T.S. Eliot: "We are the hollow men, we are the stuffed men, leaning together, headpiece filled with straw".

The Scientist, with his holistic vision, realises that ethics is a matter of inner realisation, and not adherence to external norms. Personal ethics must precede, and so be compatible with, the so-called 'professional ethics'.

However, we must recognise that most professionals are Technicians, not Scientists, and therefore emphasis on professional ethics is relevant and meaningful in today's context.

Ethics must somehow find a place (informal) in one's formal education. Integrity is naturally revealed in the teacher to the extent he has it and sees its importance. It is the Scientist-teacher alone who is capable of awakening and kindling a passion for truth-seeking in students, by integrating these thought processes with the spirit of scientific enquiry.

5.6 Motivation

Enquiry, enjoyment, creativity, sensitivity, intuition and integrity - these are seen to be the main ingredients of the scientific temperament. They are all inter-related, and come into synthesised being when certain energies are directed towards them. How are these energies harnessed in a Scientist, and why is this not possible in a Technician?

These pertinent questions are addressed by the psychologist, Abraham Maslow, in his famous theory of motivation based on need-gratification. According to Maslow (1970), "Healthy people are so different from average ones, not only in degree but in kind as well, that they generate two different kinds of psychology. The motivation of ordinary men is a striving for the basic need gratification that they lack. But for healthy people, motivation is just character growth, expression and maturation; in a word, 'self-actualisation'."

Scientists, as described in this paper, would well qualify to belong to Maslow's category of 'healthy people'; Technicians are the 'average ones', driven by the basic needs of security, money, status and power. Technicians need incentives to generate work; they are 'deficiency-motivated'. Scientists, on the other hand, are intrinsically motivated, or, to use Maslow's expression, 'growth-motivated'; they cannot help growing and maturing, rather effortlessly. They represent a high state of human evolution, where truth is sought for the sake of truth, knowledge for the sake of knowledge, and art for the sake of art. Technicians have neither the powers of concentration of Scientists nor their capacity to enjoy their work, because much of their mental energies are dissipated by their own personal pettiness and other distractions.

It is the task of the educationist to enable students to discover themselves, their needs and their potentialities. The scientific temperament in the 'have-nots' can be awakened, not by always doling out incentives, but by enabling them to recognise, accept and fulfil their inherent deficiencies.

6. Conclusions

An attempt has been made here to understand the qualities that distinguish high-quality engineering professionals from the mediocre ones. The terms, Scientists and Technicians have been used to describe the two categories. The presence or absence of a scientific temperament determines whether these professionals are Scientists or Technicians. Characteristics such as scientific enquiry, enjoyment, creativity, sensitivity, intuition, integrity and motivation make the difference between the Scientist and the Technician. Unfortunately, these are aspects that are often overlooked by engineering educators.

If the meaning of education is the full and free blossoming of the individual, and the wholesome realisation of the individual's potentialities, then Scientists can be said to be properly educated. Technicians, on the other hand, are not properly educated because they have not realised their full potential.

It is evident that our engineering education system suffers for want of Scientists as teachers. In the face of an overwhelming demand for engineering education in India, and the widespread mushrooming of engineering colleges, we end up sacrificing quality for the sake of quantity. We obviously need to ensure that we have more of Scientists as faculty in our engineering colleges.

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