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Ethics in engineering

The traditional ethical basis of engineering is well established, but the increasingly risk-averse demands of modern society pose a threat to this professional basis of virtue and trust. Brian Tomkins and Ian Howard argue that wider use of a rule-based ethic to satisfy such demands could stifle engineering innovation.

What is engineering?

Before we can attempt to address the question of ethics in relation to engineering, we need to have in mind a clear picture of what we mean by engineering. In particular we should be aware of the human forces that drive engineering and the role it plays in society. We must consider the origins of engineering, including its modern incarnation – technology.

Figure 1 shows two distinct human activities, discovery and invention, driven by two distinct forces, curiosity and need. Discovery – driven by curiosity – has relentlessly explored the 'given world' of nature and has resulted in our scientific understanding and knowledge base. In contrast invention – driven by need – has satisfied a range of human requirements for survival and for societal development. It has resulted in a variety of engineering disciplines, established on a joint basis of both knowledge and experience. The experience accumulated in creating this 'made world' has proved a hard master: countless failures and vast economic and human cost lie behind many of the successes we enjoy today. Engineering continues to shape the 'made world' as individual, national and global needs and demands change, but increasingly it is enhanced by technology.

Technology is defined as 'the application of scientific knowledge for practical purposes', but perhaps a more succinct definition today would be 'engineered science'. The twentieth century has seen technology emerge in two directions: first as a means of increasing the effectiveness of established industry sectors (for example, agriculture, mining, manufacturing, textiles, petrochemical, construction, defence, transport, power generation). In some cases separate, technology-based developments have emerged from these sectors (for example, aerospace, nuclear power). Secondly, new technologies have produced new industry sectors such as

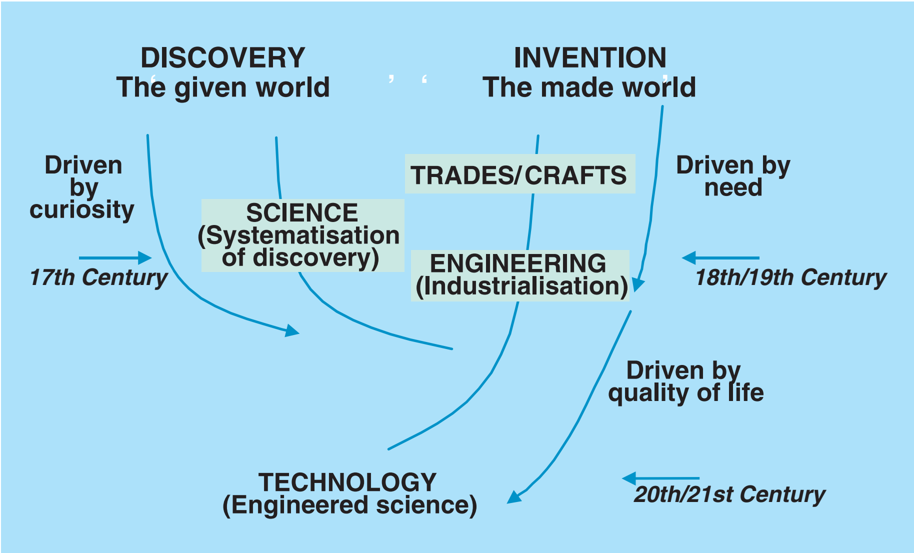

Figure 1: Origins of engineering and technology

communications, information technology, computing and biotechnology.

As Figure 2 shows, although these new industries contribute to the basic needs of society today, they are predominantly concerned with improving the quality of life, working through an ever increasing provision of services (entertainment, travel, financial, health, retail, education).

So engineering now covers a wide range of activities; engineers are trained and work across technical disciplinary boundaries and are in the forefront of innovation. In some of the new disciplines – biotechnology, for example – engineers are forced into ethical and moral debates which are difficult to resolve, whilst in established areas – transport, for example – their ability to work to the safety standards required by society is readily questioned.

In a variety of ways, as professional engineers today, we share with our professional colleagues in other disciplines (in particular health care and education) the pressure of accountability to more than just our peers. These pressures can throw doubt on the validity of the ethical basis of our profession, and we find ourselves wanting in our understanding of that basis. Ethics in engineering and technology is clearly a subject that should be aired in both the teaching of new engineers, the ongoing education of established professional engineers, and society in general.

The context of the professional engineer

Our ability as engineers to deliver the innovative designs, technical solutions and maintenance of the existing industry base that are involved in wealth creation and human wellbeing depends on our creative talents and willingness to serve in response to need. The very concept of profession is bound up with the concept of service – to the community, to society.

Competence, skill and expertise are required by all professionals, be they teachers, doctors, lawyers or engineers, and training through higher education and in-service experience equips them for service.

But who is being served? Who represents society? As far as the engineer is concerned, over time we have had many masters – society's representative being identified with the King, or the Church, or more recently by the Company or the Government. Inevitably there is an intermediary between the engineer and the ultimate customer, society. This means that as individual engineers we may fail to see the societal end point of our service, an end point which we may or may not perceive to be in the best interest of the community or society. Today, with the growth of communications, particularly through the media, the engineer may be readily portrayed as out of touch with society's need, working only for the interest of a particular intermediary, be it company or government.

In obtaining a balanced view, it is helpful to examine the professional engineer's role in the light of all stakeholders involved in the enterprise. A road map of stakeholders is shown in Figure 3. This includes those responsible for equipping the engineer, those utilising the engineer's services and those benefiting from the engineer's activity. Stakeholder

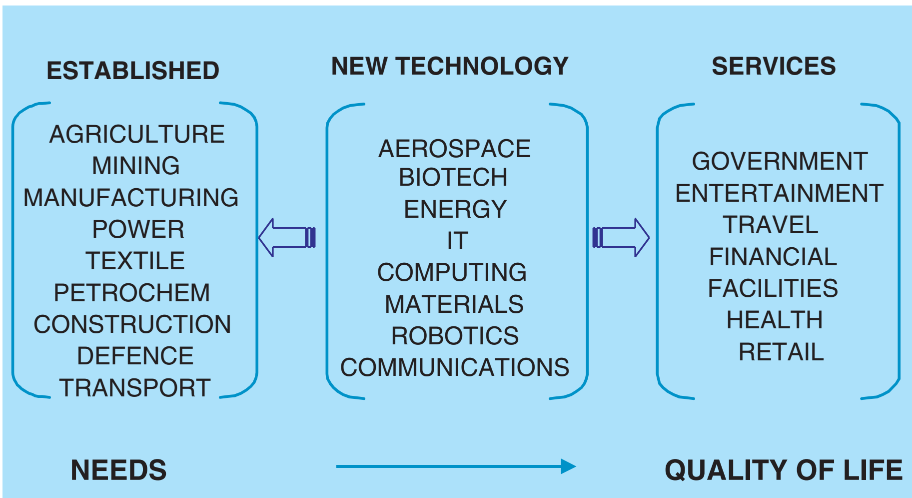

Figure 2: The role of technology in industrial development

demands may be in harmony or conflict. For example, the employer must ensure economic viability of the enterprise or project and adequate pay and conditions for employees. The government acting on behalf of society must ensure an acceptable level of safety and environmental impact. Professional institutions and higher educational establishments must ensure adequate levels of education and training.

There is a natural tension in any given project between its benefits to society and its costs, but this is not just in economic terms as it often involves environmental impact and risks to safety. Such tensions can be difficult to manage, particularly in new, rapidly developing technological or engineering ventures.

For example, the perceived benefits of national oil reserve exploitation in the North Sea in the 1970s justified rapid development of an offshore industry in a hostile marine environment, well beyond previous experience in the relatively calm waters of the Gulf of Mexico – disturbed only by the occasional hurricane. The result, despite best endeavours, was two major accidents: Alexander Keilland and Piper Alpha, as well as the steady loss of personnel working in difficult circumstances. As the industry has matured and demands stabilised, safety standards have rightly been raised to a new tolerable level.

There is a natural tension in any given project between its benefits to society and its costs

The changing dynamic between stakeholder demands is essential for a healthy society in which engineering is playing its rightful role in wealth creation and human wellbeing. But this dynamic tension must be visible as it defines the ‘tolerability of risk’ level to society for all the threats, safety, economic and environmental, which we as engineers must deal with. This tolerability level varies from society to society, because it is strongly influenced by need: need for energy, for defence, for transport, for food. An engineering plant in a developed country is likely to have a lower tolerability of risk than a similar plant in a developing country at any point in time.

The interests of stakeholders and the tensions between them set the scene for a more detailed examination of the ethical position of the individual engineer, the employer and society as a whole in the engineering enterprise.

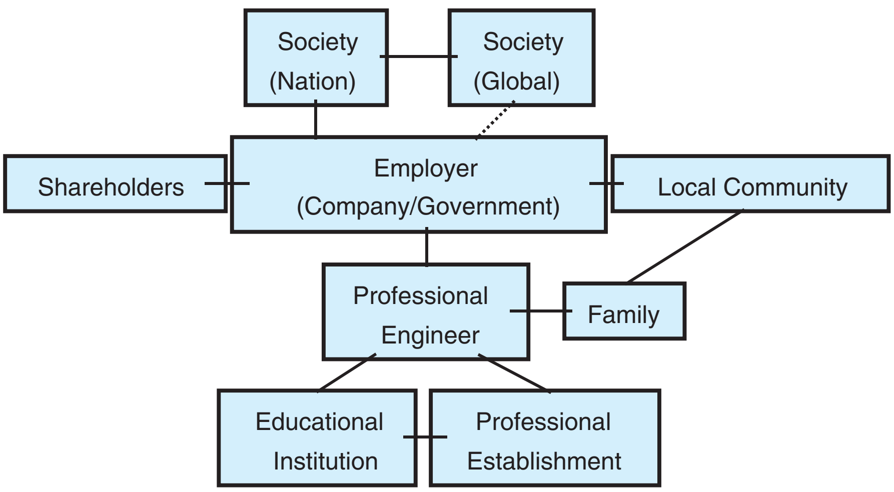

Figure 3: Stakeholder interests in the professional engineer

Position of the individual engineer

Perhaps it is as fresh engineering graduates that we are most aware of our *responsibility*; aware that being a professional engineer will mean exercising judgement, based not just on scientifically supported knowledge, but also on experience. Our personal experience is always limited, even after many years in practice, and as a profession we rely on our case history, encapsulated in Institution-backed codes and standards as the repository of good practice.

Despite this, we are always aware of limitations in both knowledge and experience which makes us instinctively act conservatively. This awareness of responsibility, strengths and limitations is the basis of the professional engineer’s personal *integrity*, which is in turn the basis of the ethic that we offer to our customers. In turn, the customer’s response is to place their *trust* in the engineer, that we will carry out the required *service* honestly and to the best of our ability.

In a complex task, the customer is well aware that several engineers may have to work together and he or she assumes that each will exercise personal integrity. Equally, we as engineers assume that we can trust the customer, and that our immediate customer contact faithfully represents the ultimate customer’s needs. This is the traditional ethical view of the professional engineer which centres on character and is compatible with a classical Aristotelian ‘virtue’ ethic, which involves the exercising of wisdom, sound judgement, courage and truthfulness. These and other similar virtues are at the heart of all professionalism, defined as service for the public good.

In an ideal world this position of the engineer and customer is perfectly acceptable. However, despite high intentions, even the best engineers make mistakes, and customers may not represent the real end-in-view of the task, which if known may be morally unacceptable to the individual engineer. In times past we accepted mistakes as part of the price of progress and it was assumed that we would learn the lessons from them. However, now they are readily broadcast, questioned and punished – 'the blame culture'.

Also in the past the structure of society was such that individual engineers did not often question the morality of the end-in-view of the tasks they were given, assuming that somehow it was acceptable to both society and to them. We now live in a society where any individual, including the engineer, can be bolder and more questioning. The world of acceptance of the simple virtue ethic in engineering is under threat. But in order to examine the threat, we must consider in more detail the context in which the engineer works; a context set by the immediate employer, be it a project or company, and by society as a whole.

Contexts of the engineer

Project, company

As professional engineers we invariably work as part of the team; even when we act as independent consultants we relate into a team activity. The project, product or service on which we work is a result of teamwork, and our individual moral stance must not conflict with that of the team. The group culture generated by any team can be a powerful force and more often than not, an individual who could not accept the team's goal would leave rather than resist. So, in order to work effectively, the team as well as the individuals in it must adopt a virtue ethic to deliver its required output, and the standard of this is ensured by an independent internal or external peer review process within the project, alongside an independent outlet for 'whistle-blowing'.

In such a way the virtue ethic is carried though a company or companies involved in major projects or directly responsible for major engineering plant or infrastructure. In engineering terms, the company's integrity is traditionally represented by the *person* of the Director of Engineering or Chief Engineer. This person carries the moral authority on engineering issues and public visibility, taking plaudits for success as well as the role of the scapegoat for failure. Any weakening of this role weakens the ethical engineering strength of the company.

Although it varies with industry sector, engineering failure is increasingly limited by the deployment of advanced technologies such as computer-aided engineering and structural integrity. As a result an increasing percentage of the failures which do occur are due to human rather than technical factors. Some are due to limitations of the professional engineer, but a significant number are the result of management failure. It is rarely the fault of an individual manager, but rather the safety culture of the organisation, set by the management.

Recognition of this in the UK has increased the demand for an effective law on corporate killing. But this should not distract us from the virtue ethic enshrined in good 'goal-based' UK legislation encapsulated in the 1974 Health and Safety at Work Act. Here the virtue ethic is clear in the premise that 'primary responsibility for ensuring health and safety should be with those who create risks and work with them'.

Society

A more informed society is a society less tolerant of failure. Today's demand is towards zero risk of engineering failure that may result in serious injury or loss of life. This demand is of course impossible; a fact recognised by all governments. But the demand is recognised and has led in the UK to the concept of a tolerable level of risk as a *goal* to be achieved. This is encapsulated in the background to the 1974 Act in the statement that 'the law should provide a statement of principles and definitions of duties of general application, with regulations setting more specific goals and standards'.

It is clear that the role of safety regulation is to set standards on behalf of society – a 'rule-based' or deontological ethic. If it is strictly enforced, a rule-based ethic replaces a virtue-based ethic and in the limit removes individual responsibility and professional integrity as the basis for the engineer's moral stance.

It has long been recognised that a strict rule-based ethic is unhealthy for society as it leads to questionable motives and the practice of rule 'bending'. It also inhibits innovation because in the absence of rules, the engineer would be in a vulnerable position. In fact the 1974 Act, based on the recommendations of the Robens Committee, provides a 'dual' ethic for engineering in relation to safety. Individual responsibility is matched with risk-based goals and there are no rules to say by what route the goals should be met. In effect, the goals are 'soft' rules. As professional engineers we are used to working in a dual ethic

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environment because our codes and standards, which encapsulate past experience, are the guidelines, even for the most innovative work. The secret is balance, whereby pressure for an increase in rules is not allowed to inhibit our engineering drives of creativity and service.

When society demands a stronger rule-based ethic to counter mistakes and failure, it is at the expense of *trust*. The chain of trust (Figure 4) from society to company to engineer and vice-versa, which should be at the heart of engineering ethics, is under threat because a media-dominated society demands exposure of higher safety and environmental risk issues. Trust can no longer be 'blind'; it must be 'informed'.

This presents a challenge to engineers and engineering/technology-based companies because we must take the initiative in communicating *trustworthy* information about significant issues. We are not alone – similar demands have come upon other professions, but there is a significant difference. For example, in healthcare, doctors and consultants are in direct communication with the customer (patient). For them the issue is regulation of their individual competence. In engineering, the balance in trust between professional engineer, the company and society requires effective proactive communication amongst all stakeholders, both directly and through efficient use of the media. We are a service business and that service must be visible.

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Engineering and ethics in practice

Engineers, as a group, are neither more nor less ethical than any other collection of human beings. Our *special knowledge*, however, confers professional responsibility for our actions. Each individual needs guidance on how this responsibility can be most effectively discharged, and knowing how other engineers have done it is helpful. The 'technical failures' literature offers useful analogies.

This compendium of the limits of what is safely attainable is a primary tool in educating engineers about the potential and limits of their *techniques*. But as we realise that our present and future generations of engineers need an analogous education as regards their *professional behaviour*, the parallel need for literature of ethical behaviour of engineers becomes increasingly urgent.

In other words, we need a fund of reliable stories illustrating how engineers can discharge their professional responsibilities while constrained by the social, political and organisational forces under which we all work. Of the few readily available stories at the turn of the twenty-first century, the two associated with the names of Roger Boisjoly and of William LeMessurier stand out both for their clarity and their outcome. The case in which Boisjoly was the leading ethical player – the space shuttle Challenger explosion – was a disaster seen throughout the world in real time. That involving LeMessurier – the design and repair of the Citicorp tower – had the potential for injuring a much larger number of people, but ended happily.

Roger Boisjoly and the Challenger disaster

The story of Roger Boisjoly's role in attempting to avert the Challenger space shuttle disaster is a contemporary classic of how an ethically minded engineer behaves when faced with powerful and aberrant forces. It is worth detailed study by everyone interested in responsible behaviour. But it is particularly worthy of study for the disturbing tale of how proper behaviour can be thwarted in organisations that have developed an irresponsible culture.

The force of the events and the implications for engineering ethics cannot be appreciated in a short summary, so anyone interested should consult the excellent reference quoted below. However, what happened, and why, can be summarised. It has the power of a Greek tragedy, an unfolding sequence of events with inexorable and terrible consequences. In this example, stakeholder tensions did reach breaking point.

The Challenger space shuttle launched from Cape Kennedy in Florida on 28 January 1986. It was the coldest day recorded in Florida history. Much of the world saw what happened

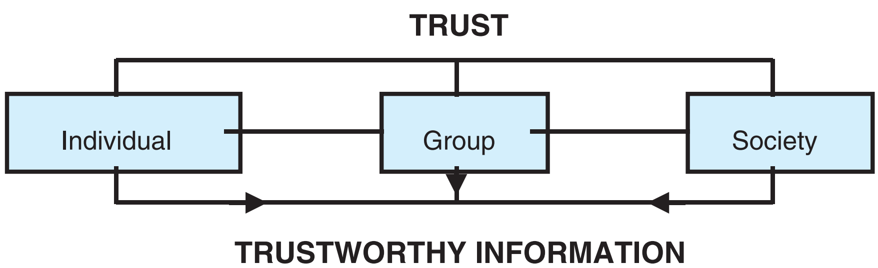


Figure 4: Links of trust and the flow of trustworthy information

The Challenger space shuttle in flight just before failure; a small flame can be seen at the site of the booster seal leak.

because this was the flight of the 'teacher in space', a major publicity event for NASA, who were deeply concerned at the time about securing future funding from Congress. Some 71 seconds after launch, the shuttle blew up in full view of millions of people worldwide linked in through the international TV systems. All seven astronauts died, including Christa McCauliffe, the teacher in space. It was just as Roger Boisjoly had been warning, in a process that he had begun more than 12 months previously. As a member of the team at Morton Thiokol, the prime contractor to NASA for the shuttle's solid rocket boosters, he had used every avenue available to investigate and report the increasingly obvious dangers associated with the O-rings that sealed the main structural segments of the boosters. Their failure, which had occurred before in flight, precipitated the catastrophe.

The high drama of a telephone conference on the evening of 27 January 1986, just before the planned launch, revealed for the first time to the engineers involved that their employer, Morton Thiokol, and NASA did not have safety as top priority. It was only after the disaster, with evidence put before the Presidential Commission into the tragedy, that the full truth of this became clear.

Boisjoly himself suffered social and professional ostracism within his company and local community but his wider standing in professional responsibility terms has been recognised and enhanced.

William LeMessurier and the Citicorp Tower

For William LeMessurier, the issues were very different. LeMessurier was, at the time of the design and building of the New York Citicorp Tower, a distinguished structural engineer at the height of his powers and professional standing. He had extensive experience in the design of skyscrapers, and was well known in his profession for effective innovation in large buildings.

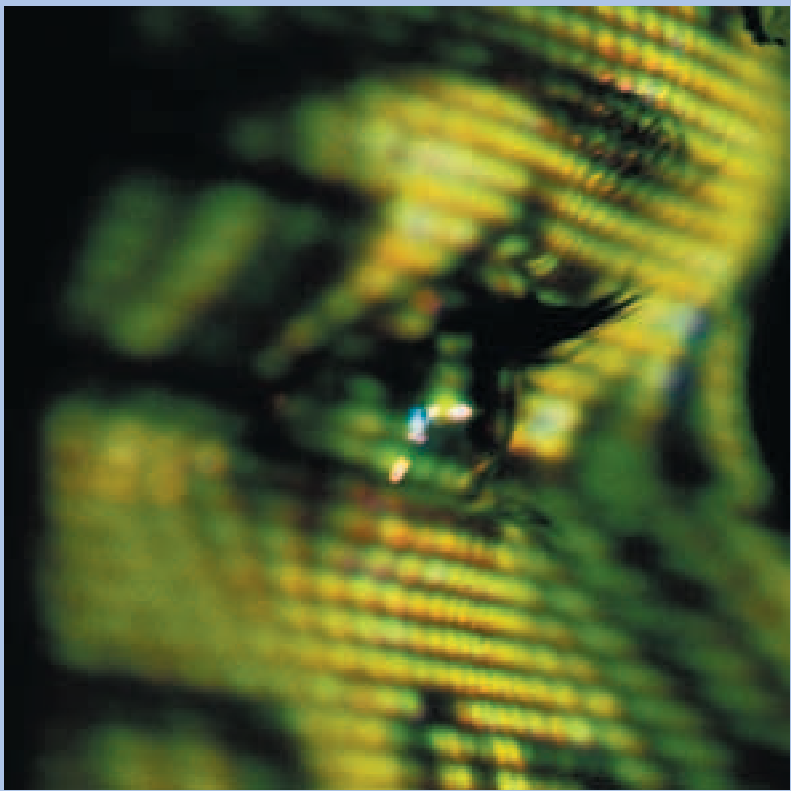
It was his firm of consulting engineers who received the commission to design the building for the corporate headquarters of Citicorp. Structural innovation was essential here, for the site contract required that space be left at ground level in one corner of the site for a new church. The congregation owned part of the block on which the Citicorp tower was to be built, and the deal would transfer the air-rights above the church to Citicorp in return for their building a new free-standing church in one corner of the site.

The story of the design of the skyscraper to fulfil these conditions, the problems that faced LeMessurier after it was built, and how he dealt with them, is, again, filled with important detail too rich to be summarised here. The reference below is, however, excellent in giving a detailed account. The essence of the problem was the replacement by the contractor of welded joints for the shear bracing by cheaper bolted joints, a practice which was allowable but produced a significantly weaker structure against wind loading.

The outcome, both for the engineered system and for the key participant, William LeMessurier, was quite different from that for Roger Boisjoly. LeMessurier managed to deal with the severe and potentially catastrophic problems of weakness in the joints of the newly constructed tower safely and without precipitating any panic. He accepted the possibility of loss of professional reputation without deviating from what he knew to be the proper and safe repair of the tower.

After this had been done, he and his firm had to face the problem of costs, for Citicorp told them that they expected to be reimbursed. LeMessurier's liability insurers had previously agreed to underwrite a figure that turned out to be only a fraction of what these costs became. If LeMessurier Consulting Engineers were obliged to carry the difference themselves, they faced financial ruin. Negotiations at senior level between all

The booster rocket 'O' ring seal used on the space shuttle



three parties resulted in the costs being born by the insurers and Citicorp only, with no blame attaching to LeMessurier. Finally, the insurers did not even raise the premium for future cover of LeMessurier, for his action had 'prevented one of the worst insurance disasters of all time'.

The Citicorp Tower, New York City

Summary

The world's engineering enterprise is underpinned by ethical principles which dictate the behaviour of the professional engineer, companies and society. Society demands more awareness of the benefits and risks in this enterprise, but care must be taken to achieve this without threatening the engineering profession's ethical basis of virtue and trust, which is a key factor in safe engineering and innovation. ■

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