The ethos of professional engineering

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Although this paper expresses the sentiments that I sought to convey when I addressed the Institution in September 2012, my ideas about the nature of professional engineering competence have developed since that time. The paper is therefore somewhat different from what I presented.

Abstract

Key features of the ethos of professional engineering competence are outlined and their relevance to the development of engineering competence are discussed.

Introduction

Professional engineers tend to have a high success rate in achieving successful outcomes in situations of complex uncertainty. I seek to identify key features that drives such success. A definition of ethos is: ‘The guiding principles and attitudes that are associated with a person, a group of people or a particular type of activity’. It is about thought processes that guide actions.

In North America the term ‘professional engineer’ is a title that a persons may assume if they have passed a test of competence in the practice of engineering. In the UK the term ‘professional engineer’ is less precise denoting a person who operates at the design and management level of engineering. The word ‘engineer’, used has a noun, tends to refer to a wide spectrum of job roles involved in the design and making of physical objects. As a verb, ‘to engineer’ has a connotation of ‘skilfully arranging for something to occur’. The paper seeks to address the question: what are the dominant modes of thinking that guide the actions of professional engineers in making ‘skilful arrangements’?

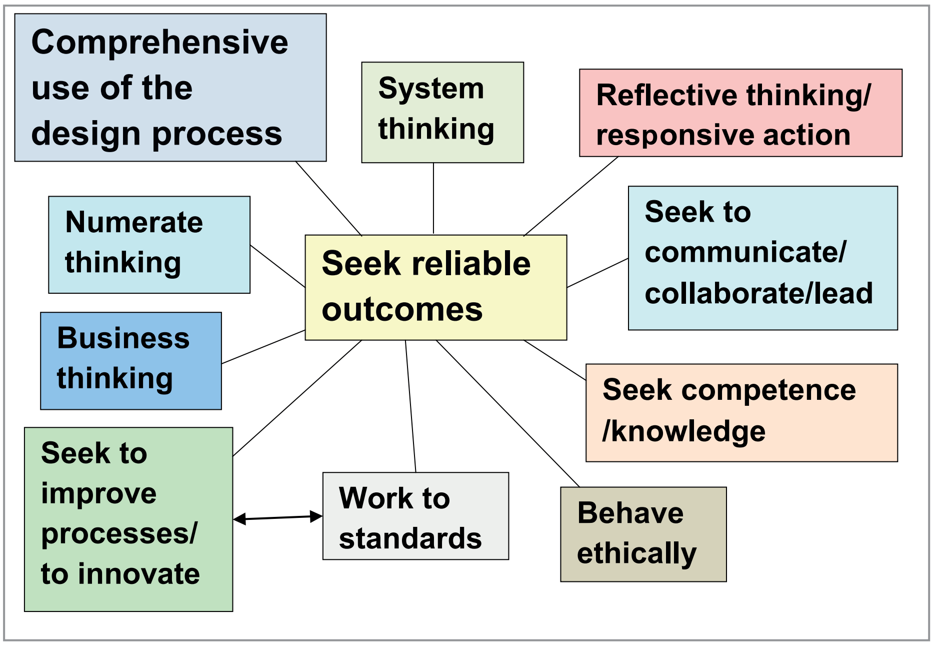


Figure 1 Features of professional engineering ethos

Features Of The Ethos Of Professional Engineering

Figure 1 shows some key features of the ethos of professional engineering. This is not a complete list. For example, Ed McCann, in his paper on Engineering Alchemy in this volume, discusses a further three features of this type.

Seek Reliable Outcomes

The types of problem that professional engineers normally have to solve - such as design problems - are non-determinate i.e. they do not have unique solutions. In such contexts it is not a matter of being right or wrong: outcomes will always be subject to uncertainty - to risk that they will prove to be unsatisfactory. A reliable outcome is one for which the risk of it being inadequate has been reduced to as low a level as is practical in the context. All relevant risks are considered: risk of failure of the system and its parts, health and safety risk, environmental risk, financial risk, etc. All strategies, methods and thought processes that can help to achieve the desired outcomes are used.

Best practice engineering adopts a relentless drive to reduce risk to an acceptable level. I identify this as the core driver for engineering success.

In order to achieve reliable outcomes it is necessary to avoid jumping to conclusions, to avoid making uninformed guesses where information can be made available.

Comprehensive Use Of The Design Process

What is referred to here as the 'design process' is a universal strategy for solving non-determinate problems. Although the language used to describe it varies, the underlying process tends to be invariant. It can be expressed as have three stages - Figure 2:

- Inception - where the requirements are established and information about the context is gathered
- Conception - where a range of options that have potential to satisfy the requirements are defined and compared, leading to a decision about the form of the solution
- Production - where the solution is fully formulated.

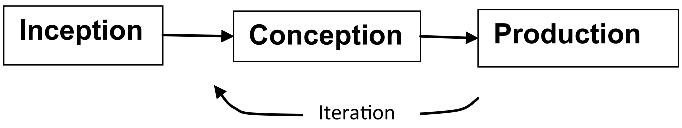


Figure 2 Stages in the design process

The line with the arrowhead on Figure 2 indicates that the process is normally iterative. Further requirements may emerge as the process develops and the solution may prove to be unsatisfactory at the production stage.

While people use the process intuitively e.g. when shopping or deciding what to have for dinner, when engineers need to make important decisions they tend to adopt a comprehensive approach to its use. This infers that all relevant aspects of the context are addressed in ways that seek to lead to reliable outcomes. For example, guiding principles in the use of the design process include:

- Identify the requirements of the project such that all issues that may affect the outcome are addressed
- Gather information about an appropriate range of options to a level that they can be adequately assessed. In some cases a large number of options are considered.
- Use all methodologies that can help to improve the reliability of outcomes.
- Carry out a careful assessment of the options against the requirements to seek to ensure that the form of solution chosen is the most appropriate that can be devised.

These guiding principles can be considered as part of the ethos of professional engineering.

Core activities in engineering are set out in Table 1. These are:

- To create a physical object one first of all devises a set of models of it. The models can be graphical, written, mathematical, etc. This is design. The design is then used to make/manufacture/construct the object.
- Management can be defined as planning and administration of processes. (A process being a means by which an objective may be achieved.) The plan is a model of the process just as a design is a model of a physical object. Administration is control of the implementation of the plan
- Investigation is consideration of the condition of existing entities. This is a type of process that needs to be planned and performed.

Activity	**Model**	**Implementation**
Create physical objects	Design	Make
Manage	Plan	Administer
Investigate	Plan	Perform

Table 1 Core activities in professional engineering

The framework set out in Table 1 and the associated definitions represents a highly simplified model of engineering activities. Design is a process that needs to be managed. Design and planning are basically the same activity: they are both exercises in modelling to which the design process of Figure 2 is applied. The words 'planning' and 'design' can be used interchangeably. For example, software engineers use the word 'design' in the planning stages in software development. A comprehensive approach to all the activities is needed.

Reflective Thinking - Responsive Action

Reflective thinking is about asking questions. Professional engineers exhibit a healthy scepticism about received and generated information and a curiosity about all things. Answers to questions such as: 'Is that right?', 'Is the evidence for that solid?' are constantly sought. Observations such as 'That does not look right' are made where appropriate. Since when working in situations of complex uncertainty it can be difficult to get it right first time one expects faults to be found at all stages of processes.

When faults are identified responsive action is needed. A common reaction to finding that one has made an error is to seek to hide it. This is entirely wrong. One's personal attitude and the ethos of the organisation in which one works should be that taking action to correct faults is more important than personal pride.

It is important to:

- adopt a humble approach accepting that other people may have better ideas than your own but balance this by having confidence in your own ideas when appropriate.
- seek widely for support for your work including from other disciplines if appropriate
- accept that despite all efforts, outcomes that you have achieved may not be fully fit for purpose and that amendments may be needed
- seek/welcome independent scrutiny of what you are doing or have done.

Numerate Thinking

The American Engineers' Council for Professional Development defines professional engineering as: 'The creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes,...' This puts science at the forefront of professional engineering activity. While it is not suggested that use of science is other than very important in engineering, Figure 1 suggests that it is not the core issue.

Photo by Chris Morris, from *Thomas Telford's Scotland*

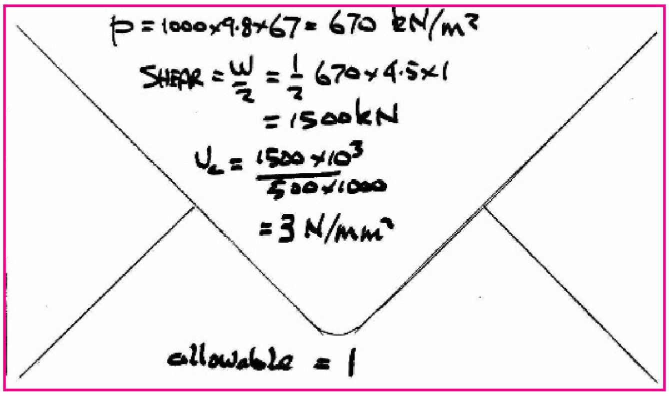
Engineers of the past had limited scope in in the use of science as compared with what is now available. For example, Thomas Telford was disappointed that the applied mathematicians of his day were unable to give him much help in the design of his great works. His Craigellachie Bridge (pictured) and the Menai Straits Suspension Bridge are exceptional examples of the art of engineering in the absence of the use of modern structural mechanics which only started to emerge at the very end of Telford's life[1]. Since that time and especially with computers to do the calculations, the use of scientific methods: (a) has allowed spectacular levels of innovation - for example, Clerk Maxwell's equations of electromagnetism underpin the developments in communications from which we now benefit and (b) creates much higher levels of safety e.g. in the design of bridges.

The guiding principle in relation to numerate thinking is that if predictions and measurements can help to achieve reliable outcomes, they are used.

Predictive Modelling

A predictive model seeks to estimate the future behaviour of a system. Doing this is one of the great achievements of the human intellect. We are able to see into the future. But often such vision is not in sharp focus. In the drive for reliable outcomes, the use of predictive models is treated as a major tool for reducing risk but, because of inherent risks, a reflective approach to their use is adopted. Careful validation of models (consideration of whether the model is able to satisfy the requirements) and verification of results (consideration of whether the model has been correctly implemented) are essential activities. In 1992 the Sleipner concrete oil production platform, Figure 3(a), sank in a Norwegian fjord resulting in total economic loss of the order of 700 million dollars[2]. The failure was due to an error in the model for the prediction of the structural behaviour. Use of the back of an envelope calculation (resulting from reflective thinking) shown in Figure 3(b) could have prevented this loss.

(a) The Sleipner Platform prior to collapse



(b) ‘Back of an envelope’ check for stress in cell wall

Figure 3 The Sleipner Platform

Performance Monitoring

Where potentially useful data is available it is used to achieve good outcomes. Developing a product on an incremental basis based on performance data is a very important strategy in engineering.

In the manufacturing industry it is common to make a prototype - say for a car - and test it hard to find faults and correct them before the launch to market. This strategy should be adopted if feasible. In the construction industry where facilities are mostly large and one-off, the use of prototypes is restricted.

Once the product is released for sale the monitoring process continues to identify and correct faults. For example, modern airline pilots are unlikely to experience an engine failure in their career. This is because the risk of such failure has been reduced to a very low level by preventative maintenance based on performance monitoring.

System Thinking

The underlying principle behind system thinking is that in order to have a comprehensive view of the behaviour of a system, it is necessary to address how the parts work together to create the whole. For example, the need for a system approach to planning for an electricity system is explained in Paper 1668 in this volume.

In system thinking all the issues that can affect outcomes are considered: the behaviour of the system, the behaviour of the parts, the overall concept, the details.

System thinking should embrace long term thinking by taking account of lifecycle issues.

Innovate/Work With Standards

While it is true that innovation is a core feature in the success of professional engineering it is also true that a main strategy for controlling risk is to repeat successes and avoid repeating failures i.e. not to innovate but to play by the rules. Engineers develop codes of practice that can be international, national, industry sector standards or in-house procedures. It is normal to adhere quite strictly to such standards. Innovation leads to higher levels of uncertainty about outcomes resulting in special care being needed to achieve satisfactory outcomes.

Innovation is used to improve engineering products but improvement in the processes used is also of the highest importance. A constant drive to improve both products and processes is central to engineering success. But when a process has been established it is also very important to follow it as specified. One should only change a specification (a) if this will result in an improved outcome and (b) the change is by agreement with parties who may be affected by such action.

Therefore a fundamental dilemma in professional engineering work is that one must look both ways:

- to constantly seek improvements
- to work to rules and follow specifications to the letter.

Different mind-sets are needed for working with standards and generating new approaches. The generation of creative ideas may need free thinking where being wrong is not a fault, whereas in implementing the ideas a focused approach is needed so that outcomes will be fit for purpose.

Ethical Thinking

A central plank of professional behaviour is to work to a code of ethics. Unethical behaviour by professional people has a very negative effect on society. The Statement of Ethical Principles[3] drawn up by the Royal Academy of Engineering and the Engineering Council and adopted by IESIS lists ‘four fundamental principles that should guide an engineer in achieving the high ideals of professional life’: Accuracy and rigour; Honesty and integrity; Respect for life, law and the public good; Responsible leadership.

Consideration of the natural environment, the social environment and sustainability are pervasive ethical issues in engineering practice.

Some ethical issues are passive: there are things that one should not do such as not taking bribes or not compromising public safety on the basis of client requirements. There is also an active component - e.g. a responsibility to seek to improve the quality of life and to limit negative effects on the environment.

Seek Competence/Knowledge

Having wide ranging knowledge and specialist knowledge are key attributes of successful engineers. One cannot have too much knowledge. One should constantly seek to improve your own knowledge and competence and that of others whose work you direct.

Collaborate/Communicate

The success of projects is heavily dependent on the quality of collaboration as well as on leadership. Engineering projects increasingly require major collaborations across disciplines. Learning to work with other disciplines from the earliest practical age should be sought.

While major roles in leadership tend to be assumed later in careers, this is an important issue at all levels. Young engineers working on a shop floor or on a site often need leadership skills. It is important to understand the principles of good leadership and team work from an early age.

While deep knowledge of other disciplines is not required, appreciation of the general principles is advantageous. Guiding principles include: that support from other disciplines should be sought where appropriate, respecting the stances taken by people from other disciplines and keeping an open mind about their contributions.

Business Thinking

Business issues are integral to professional engineering practice. Consideration needs to be given to the principles of client focus, costing, cost control, finance, developing contracts and working with contracts, negotiation, entrepreneurship, selling services or products, etc.

The Role Of Ethos In Professional Competence

The standard UK model of engineering competence, UK-SPEC[4], defines competence mainly in terms of what engineers do whereas Figure 1 focuses on how engineers think. Figure 1 is intended to be complementary to UK_SPEC. Most of the features shown in Figure 1 can be identified in UK_SPEC.

Professional engineering competence is too complex to be fully defined. Seeking to define it is like trying to identify the interior of a large building by only looking in the windows from the outside. Each window gives a different view and some parts of the building are not visible from any window.

Figure 1 and the associated discussion seeks to provide a view of one of the 'rooms' of engineering competence.

It is being realised that how engineers think is an important issue in engineering competence . For example, reference 5 gives another view of how engineers think.

Ethos In Engineering Education

The traditional ethos of engineering education is quite different from best practice engineering ethos. For example, educational experience tends not to instil the need to work to a specification, to do what is required - to the letter. Some people do this naturally but possibly most need to be trained to do it. Getting only 40% of the outcomes right is totally unacceptable in the real world.

Because there was very little project work in traditional engineering courses, opportunities to develop an engineering practice ethos were very limited. Engineering courses now have increasing amounts of project work that provide opportunities to develop the ethos needed to support engineering competence. Providing opportunities and support for the development of good engineering thinking should be a core objective of engineering courses.

Engineering Ethos In The Wider World

One could say that the features of engineering ethos set out in Figure 1 are relevant to all who seek to produce reliable outcomes in contexts of complex uncertainty.

Conclusion

I have used the word 'ethos' to denote the component of competence that is related to guiding principles and attitude. It relates more to how engineers think rather than to what they know and do. Ethos is not absent in conventional models of competence but it tends not to be treated explicitly. Addressing how engineering ethos can be defined and fostered in engineering practice, and in education, is a central issue in the development of competence. The discussion of the features of ethos in this paper is intended as a contribution to the debate about how to define it.

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