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System planning in government and in education

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Abstract

Over thirty years ago, I posed myself this question: "What are the processes and guiding principles that support the success of professional engineering outcomes?" I needed answers to that question to inform research work in computer aided design and also to help students to develop their professional competence. My quests for answers has continued over the years. I have re-phrased the question to be more generic: "How are successful outcomes achieved in situations of complex uncertainty?" and I use the term system planning to represent the processes and principles. I offer here some answers to the this question.

Consideration of the wide use and success of system planning in society, raises two further questions: First: "Why do we allow politicians to go ahead with strategies aimed at solving problems of very high complexity that have not been subject to system planning?" Second: "Why is learning for system planning not a main activity in education?" In the paper, I provide some thoughts on the second of these questions that may also provide some answers to the first.

Iain A MacLeod

1. Introduction

I define *system planning* as 'methodical achievement of outcomes in situations of complex uncertainty'. Such outcomes can be in relation to a wide range of situations such as the creation of a physical system, for example an engineering product, the creation of a process, for example a business process, or a change in a state of affairs, for example reduction in the use of fossil fuel. The fundamental aim is to make the future better than the past. Box 1 gives examples that illustrate the principles.

Use of the word 'system' implies a systematic approach to the development and use of the processes involved and to the use of 'system thinking' where the performance of systems and of their parts is taken into consideration.

Some of the important features of system planning are shown in Figure 1 and are briefly explained in Section 2

Abiliity to plan and think strategicaly, i.e. to do system planning stands beside communication methods and manual dexterity as a characteristic that distinguishes *homo sapiens* from other animals. When it is successfully used to address situations of high complexity and high uncertainty, it is one of the most intellectually demanding of all human activities.

While examples of successful system planning are widespread in engineering, in medicine and in business, we also see many situations where the principles are neglected. In particular, governments seeking to address major global issues such as environmental degradation and inequality often fail to use system planning principles – Section 3.

Education should seek to ensure that learners in all disciplines – and particularly those who aspire to hold responsible positions in society – develop system planning skills.

Box 1 Examples of how outcomes are achieved

1. Intended outcome: Have food in your house

Sue and Jack Brown have well-paid jobs. The cost of food is not important to them and they do not worry much about nutrition. To stock up on food, they go to a supermarket, select items as they walk along the aisles, pay, and go home. They keep the process as simple as possible. It is mainly tacit.

Claire and Joe Green are on a tight budget. Before starting to shop, they prepare a list of items to purchase and decide to shop around to get better prices and to take account of nutritional value, fair trade, animal welfare and sustainability. For each purchase, they look carefully at options in relation to these issues. After doing their shopping, they keep a record of their purchases and use this information in making future decisions when buying food.

The Greens are much more explicit and systematic about their shopping as compared with the Browns. This makes their process more complex and, since low cost and high quality are normally competing requirements, it raises the level of uncertainty about choices. They work as a team to seek to ensure that the food in their house is well suited to their preferences. They adopt system planning principles such as being explicit about objectives, doing options analyses and keeping records to inform future purchasing decisions.

2. Intended outcome: Put a man on the moon

In the 1960s, the USA committed about 2% of its Gross Domestic Product for a period of 10 years to the strategic objective of putting a man on the moon. Many interconnected systems had to be designed and implemented. They were all carefully tested. The parts were tested; the systems were tested; unmanned flights were carried out. The levels of uncertainty, complexity and risk were of a very high order. There was deep collaboration: the intellectual capital of the nation was harnessed to the task. People with high levels of competence and leadership were recruited, e.g. in political administration (James Webb) and in technical/project administration (George Mueller)[1]. There was deep commitment to achievement of the goals.

2. Features of system planning

In a system planning situation there are no fixed rules. Processes need to be customised to the context, not all of the features listed on Figure 1 may be relevant but other features may need to be addressed.

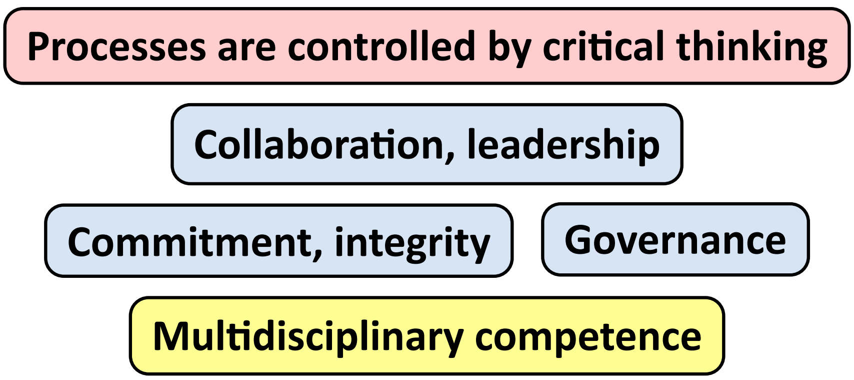

Figure 1 Typical features of system planning

1 *Johnson S B, The Secret of Apollo, Johns Hopkins University Press, 2006*

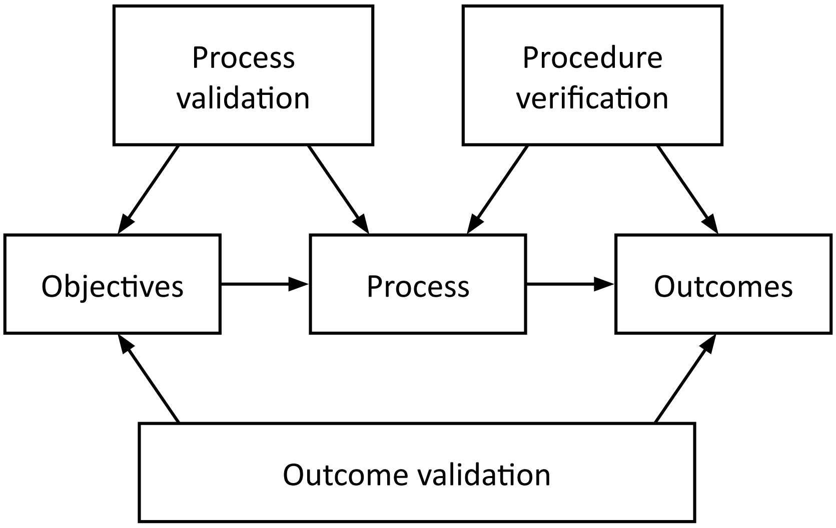

Figure 3 Validation and verification

Critical thinking

Critical thinkers constantly seek to identify and use principles that will lead to successful outcomes. An ethos is defined as 'the principles and attitudes that are associated with a particular type of activity'. In a previous article I implied that critical thinking is the overarching ethos for system planning[2].

A crucial principle is the adoption of a reflective, contemplative ethos where questions are posed, responded to and which result in appropriate actions. Those involved review, consult, challenge, expect to be challenged, are sceptical about all information, avoid preconceptions and bias and are prepared to change their minds on issues.

Other guiding principles in a system planning ethos include:

1. Test all proposals to the extent that is appropriate in the context.
2. Adopt a systems approach where the behaviour of the system and of its parts are addressed.
3. Adopt a holistic approach where all relevant issues are addressed.
4. Define the objectives in terms of what is to be achieved rather than how it is to be achieved.
5. Identify guiding principles and state them clearly.
6. Look widely for advice but be wary of bias in what is received.

In team working, the principles should be made explicit so that everyone involved in the process can adopt them[3].

Process control

A process can be viewed as what is done to transform a set of objectives into outcomes. Controlling a process means taking action to ensure that the process achieves the objectives – mainly by posing questions about its efficacy with the intention of seeking to improve it.

A *procedure* is an established process with fixed steps.

Validation and verification are important actions in process control

Process validation is to seek answers to questions such as: 'Is the process capable of satisfying the requirements? Is this the most appropriate process in the context?' *Outcome validation* is to seek answers to the question: 'To what degree do the outcomes satisfy the objectives?'

Procedure verification is to seek answers to the question: 'Has the procedure been correctly implemented?' This question is used after the process has been established as a procedure.

In determinate situations where processes are predefined, process validation is not normally required. When working with the inherent uncertainty of system planning, process validation is of great importance because, since every situation is different, a procedure that worked in one context may not be suitable in another apparently similar situation.

2 *https://eit.engineers.scot/index.php/Critical_thinking*

3 *Macleod I A, Leadership and ethos in complex problem solving, IES Journal, Vol 158, 34-37, 2019 https://library.engineers.scot/files/original/1abcc4e75de630d47cd1f08c61304860.pdf*

Risk control

While the purpose of system planning is to achieve good outcomes, a fundamental strategy for doing that is to to take action to prevent unsatisfactory outcomes – i.e. to control risk. As well as using formal risk control methods, reflective questioning, that is a main feature of critical thinking, can be viewed as a strategy in risk control. For example, it is often wortwhile to pose 'What if?' questions.

Problem solving processes

Two basic problem solving strategies[4] are: bottom-up and top-down.
In bottom-up, one uses rules to synthesise a result. For example, in mathematics a quadratic equation such ax^2 + bx + c = 0.0 can be solved using the expression:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

For top-down, one proposes options and tests them for suitability. For example, for a differential equation such as

$$a\frac{d^2y}{dx^2} + b\frac{dy}{dx} + c = 0.0$$

there is no formula that will result in a solution: one has to guess a solution and test whether or not it is valid. Top-down is a searching process.

In problem solving, situations are either determinate or they are not determinate. *Determinate* implies that there is at least one outcome that can satisfy the objectives precisely, where logic alone is sufficient for the assessment of solutions. For example, the solution of a quadratic equation is determinate. On the other hand, in a situation that is *not determinate*, there are no outcomes that meet the objectives precisely and acceptance of an outcome has to be based on judgement, requiring the use of logic plus evidence. The term 'not determinate' does not imply that the matter cannot be resolved. It does imply that there will always be uncertainty about the suitability of outcomes.

The problems that are addressed in education for mathematics and science, are predominantly in situations that are determinate and for which bottom-up solutions are feasible – such as the solution for the quadratic equation, whereas in system planning, the contexts are not determinate and top-down is the only feasible strategy.

Use of the top-down strategy in system planning

Three basic stages in the top-down strategy are shown in Figure 4.

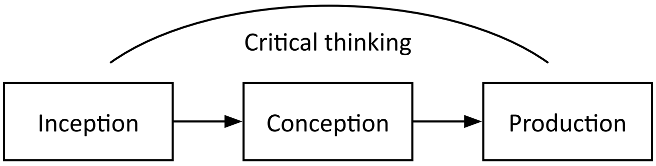

Figure 4 Basic stages for the top-down strategy

The stages are defined as:

- I Inception – Define the strategic objectives
- C Conception – Devise courses of action to achieve the objectives.
- P Production – Implement the courses of action to achieve the outcome

In Figure 4 Critical thinking is shown as an overarching concept that integrates the stages and supports the systematic nature of the work. A fourth stage in often added to the list to represent feedback. For example 'outcome validation' in Figure 3 can be thought of as a stage but it is important not to treat the stages as being clearly bounded. Forward consideration of later stages, and feedback to previous stages, are very imporant features of the critical thinking ethos.

As an example, suppose that the objective is to create a building. In Figure 5(a) the *project process* is the overall process to achieve the outcome. 3 stages/subprocesses for the project process are shown:

- The strategic objectives (Inception) are in the form of a client brief.
- The outcome of the design stage (Conception) is information about what the building will be.
- The building is created at the construction stage (Production)

Each of the stages involves use of the top-down strategy. For example, the design stage (Figure 5(b) for a building starts (Inception) by developing the client brief into a project brief that defines the requirements (the objectives and constraints) for the building. This is followed by a concept design stage (Conception) where a range of design solutions are considered leading to a decision about the general form of the building. Then the drawings and specifications for the building are prepared (Production). This output becomes the input to the construction stage that is also subject to the top-down strategy.

4 Macleod I A, To Engineer, Institution of Engineers in Scotland, 2017, https://engineers.scot/office/resources/publications/to-engineer.pdf

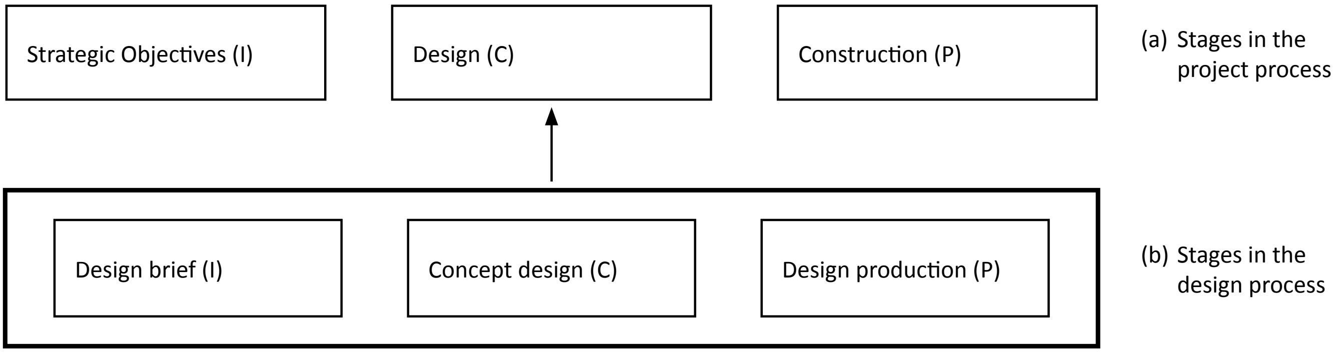

Figure 5 demonstrates the *recursive* nature of the top down strategy where sub-processes, e.g. the design process, is part of the project process but also has its own ICP stages.

The basic stages in the top-down strategy are relevant in all situations because they follow logically from the need to test proposals. But every time the strategy is used, it will be different – because the situation to which it is applied will be different.

The stages are given different names; normally more than 3 stages are defined and the boundaries between the stages tend to be flexible. For example: clinical psychologists use the names: "Assessment, Formulation, Treatment and Evaluation" for the stages in their treatment process; in quality circles (for example in ISO 9001[5]), the names of the stages are: "Plan, Do, Check, Act".

The process does not always follow directly through the stages because feedback loops, triggered by critical thinking, can occur at any point.

Making well-informed judgements

Proposals for action are normally made on the basis of judgements that should be informed by logic and evidence derived from testing.

Making an untested proposal for action, i.e. jumping to a conclusion, is strictly avoided.

The suitability of a judgement depends on the quality of the information available and the quality of the methods used in making the evaluation. Good judgements are critically dependent on good information.

Multidisciplinary competence

The range of disciplinary skills that are drawn on to address complexity is another very important feature of successful system planning. This applies especially to the key members of the team.

Collaboration, leadership

A fundamental principle for successful system planning is that, because of complexity, it is unlikely that one person will have all the necessary expertise and the work is normally carried out by multidisciplinary teams. That the team works in harmony, is crucial to the achievement of successful outcomes.

Autocratic managers make independent decisions, prefer not to consult with others and seek to marginalise those who challenge their decisions. Collaborative leaders seek consensus from the team. They expect their ideas to be challenged by others.

By failing to take advantage of the intellectual capital of the team, use of an autocratic style of management increases the risk of unsatisfactory outcomes as compared with a collaborative approach.

Being able to work together and to lead teams that focus on achieving the project objectives, are special skills that are best learned at an early age.

Commitment, integrity

Commitment to the goals of a project implies that one puts aside considerations that are not consistent with the goals. For example, it is normal for people to be inhibited about admitting to mistakes, to prefer to tell senior colleagues what the latter want to hear rather than the truth or to be biased towards actions that serve their own interests. Such thoughts cannot be banished from one's mind, but in system planning, positive action should be taken to prevent them from adversely affecting outcomes.

Integrity is the degree to which one acts in accordance with ethical principles. Maintaining an ethical stance in all activities is crucial for a fair society.

5 *ISO 9001:2015 Quality Management Systems*

Wise Governance

Governance represents the processes by which decisions are made and implemented. Responsibility, authority, accountability are core issues in governance.

A key principle in governance is that when acceptance or rejection of proposals is the responsibility of senior management or of a client, changes to proposals generated using system planning should only be made on the basis of further proposals that have also been thoroughly tested.

3. System planning and government decision-making

In November 2020 the UK Government issued a press release[6] that stated "PM (Prime Minister) outlines his Ten Point Plan for a Green Industrial Revolution for 250,000 jobs."

Although many would have been involved in preparing the plan, the press release infers that the Prime Minister formulated the plan. He had, for example, the authority to change a target date in a draft plan to his own preference without being required to justify the change. Government ministers are expected to make decisions in this way but it is highly inappropriate that they should do so.

But energy planning involves complex technical and safety-critical risks, where the consequences of error can be dire. Is it acceptable that a person with no qualifications or experience in the matter has authority to act on untested proposals? In most professional contexts such decision-making would be considered to be unacceptable. For example, suppose you have a serious medical problem. Would you prefer to be treated by a lawyer or by a team of highly competent medical people? It would be absurd to make the former choice but major decisions are made in politics on the basis of proposals from people who may lack even basic training in the subject.

When the Ten Point Plan was issued, it was not backed-up by reference to reports that demonstrated the feasibility of meeting the emissions reduction targets. If such studies were not carried out, the Plan was not based on system planning methods.

The appropriate strategy for major government decisions is to separate the responsibility for making major proposals for action from responsibility for deciding whether or not proposals be accepted. The proposals for action should be formulated by a multidisciplinary team. Acceptance (or rejection) of major proposals should normally done by ministers or by Parliament. They are elected to make decisions about the allocation of resources. Making decisions based on proposals made by specially appointed bodies would not reduce the authority of the government or of Parliament, but it would reduce the risk of unsatisfactory outcomes.

Such a process is used by government. For example, proposals for the Queensferry Bridge over the River Forth were prepared by a multidisciplinary design team led by government staff. The proposals were approved by the Scottish Parliament. It was obvious that, due to the technical complexity and safety-critical nature of a long-span bridge, government ministers would not feel competent to force changes to the specification. Energy planning should also prompt that reaction. Indeed, all actions by government should be based on system planning principles.

A main role of government is to mould the future to the needs of citizens and of the environment. Action by governments has the greatest potential to address issues such as environmental degradation, inequality, resource depletion and climate change, that are characterised by very high levels of uncertainty, complexity and importance. In the absence of system planning by governments, the likelihood of success will be significantly compromised.

The adoption of a system planning ethos would provide an opportunity to reduce the democratic deficit in Parliament that stems from the executive power of ministers. Before deciding on proposals, the Government would seek responses from the public to documentation explaining the logic and evidence that had been used. Such public scrutiny would significantly improve accountability.

4. System planning and education

In order to learn for system planning, it is necessary to carry out project work. Later In this section, I suggest that the level of project work in seconary education and in university education is low. Therefore learning for system planning is not a core activity in education.

Ability in system planning is is crucially important in society and is an innate feature of healthy human brains (see Box 2) that artificial intelligence is not close to mimicking. Why is it not well-nurtured in UK education?

According to Donald Schön[7], all professions had to make an unsatisfactory compromise to gain academic recognition. He wrote (p21):

6 *https://www.gov.uk/government/news/pm-outlines-his-ten-point-plan-for-a-green-industrial-revolution-for-250000-jobs*

7 *Schön D, 1984, The Reflective Practitioner: How professionals think in action, Basic Books,*

> *"According to the model of Technical Rationality – the view which has most powerfully shaped both our thinking about the professions and the relations of research, education, and practice – professional activity consists in instrumental problem solving made rigorous by the application of scientific theory and technique."*

Schön's argument was that the professions had to accept that university learning would be based on the principles of technical rationality but he noted (p39) that:

> *"Increasingly we have become aware of the importance of complexity, uncertainty, instability, uniqueness, and value-conflict – which do not fit the model of Technical Rationality."*

in his 1982 book *The Reflective Practitioner: How professionals think in action*

Although scientific theory can help to make professional practice more rigorous, use of such theory is only one of the strategies used in professional decision making. An educational programme that focuses on technical rationality does not address the range of skills needed in professional practice.

Presumably Schön was writing about the situation in USA. I do not have information about education for professions in the UK apart from engineering where, as I now explain, the philosophy behind the early degrees was undoubtedly based on Technical Rationality – as defined by Schön.

Box 2 *Homo sapiens* and the frontal lobes of the brain

We often compare ourselves to animals in a superior and arrogant manner. This notion is simplistic and overlooks various superior skills that animals possess in relation to their human counterparts. Such skills have evolved over many years to assist them living in the wild, for example superior sensory capacities, such as an advanced sense of smell or hearing, which far outstrips our own.

Nevertheless, our broad capacity for complex problem solving and intellectual functioning is certainly superior to other animals. There are complex neurological reasons for why this is the case, but one of the areas that is proposed to set man apart from other animals is the frontal lobe, located at the very front of the head. The structure and function of the brain in animals is surprisingly similar to our own, but one distinct difference is that our frontal lobes are far larger than other animals. The frontal lobe governs complex behavioural interactions, and cognitive processes, including planning, advanced problem solving, social processing, and the governance and control of our impulses. When we drink alcohol, the functions of the frontal lobes are stunted; we lose the ability to logically appraise our surrounding and there are no "brakes" to control our impulses. We have been blessed with the capacity to assimilate and process complex information, and we need to harness this ability in a manner to benefit individuals and communities alike.

M Albiston, clinical psychologist, Personal communication, November 2022.

Engineering Education in the UK

In the nineteenth century, William Rankine, the Professor of Engineering at Glasgow University and first President of IES, struggled to get agreement by the University to offer degrees in engineering. In 1872, he accepted a proposal for a degree in engineering science[8]. The University would not allow the practice

8 *Small J The Institution's first president, IES Journal https://library.engineers.scot/files/original/ca6500f8c480535a5f97d7c48d30597d.pdf*

of engineering to be included in the curriculum. It is unlikely that the term 'Technical Rationality' was used to justify this arrangement but the study of science was deemed to be suitably rigorous whereas the study of engineering practice was not. This was the view across the UK university sector but it was seriously misguided. Progress in UK engineering education was held back for over a century by this philosophy because:

- System planning, the fundamental issue in engineering practice, requires intellectual activity of the highest order.
- Use of science is only one of the techniques used by professional engineers.
- Learning the science in the absence of how to use it is like going to piano lessons and finding that there is no piano on which to practice.
- Learning to *use* the science in practical situations provides purpose. People tend to be better motivated to study when the purpose of what they are doing is evident
- Attitudes that are important in system planning are best developed from the earliest practical age.

Based on the recommendations of a 1980 UK government report[9], learning for engineering practice became a requirement for university degrees in engineering. All UK university engineering courses now incorporate project work in the curricula.

School education

'Capacities' intended to be developed via Education Scotland's Curriculum for Excellence[10] include:

- Apply critical thinking to new contexts
- Develop informed, ethical views of complex issues
- Evaluate environmental, scientific and technological issues
- Make reasoned evaluations
- Assess risk and make informed decisions
- Work in partnership and in teams
- Take the initiative and lead

These capacities are in strong alignment with the features of system planning discussed in Section 2. In order to develop such capacities, it is necessary to work on projects. Project work is the essential context for learning for system planning because it . Most projects have potential for learning to develop system planning skills.

Primary school

Apart from disciplinary competence, the system planning skills listed in Figure 1 are strongly dependent on ethos, i.e. on attitudes. Attitudes tend to be easy to establish when young and it is therefore preferable to start to learn system planning skills from an early age, i.e. in primary school.

Project work is already a feature of primary school learning. Day to day tasks can be used for practice – see Box 1. Older pupils can be introduced to methods of working with uncertainty at low to medium levels of complexity. They can learn to be critical thinkers, to be explicit about objectives, to do options analysis, to measure/assess outcomes and to reflect on how situations might be improved. For example[11], a primary school head teacher required her senior pupils to make a report on the suitability of the layout of their school to be used for briefing an architect for a new school. This is a very good example of learning to reflect about a situation that was within the experience of the pupils.

Secondary school

The breakdown of learning in secondary schooling into subjects with clear boundaries and the focus on knowledge acquisition makes it difficult, but not impossible, to introduce project work Having a subject that involves only project work not tied to particular subjects would be worthwhile. There are design subjects in the Scottish secondary school curriculum that are related to engineering and to art but the principle that design is part of a wider process in the achievement of successful outcomes, needs to be more fully addressed. Overall, the level of project work in secondary education appears to be low.

The need for STEM (Science, Technology, Engineering and Mathematics) learning is widely promoted. When discussing the objectives of STEM, it is common to link it to 'key skills' such as critical thinking, problem solving, creativity, teamwork, i.e. to the skills needed for system planning. However, learning in the STEM subjects tends

9 *Engineering our future HMSO, 1980*

10 *Education Scotland https://www.education.gov.scot/Documents/btc4.pdf, 2009*

11 *MacLeod I A The discipline of critical thinking, IES Strategy paper, 2020, https://www.engineers.scot/office/resources/publications/discipline-ct.pdf*

to be focused on knowledge acquisition and the solution of determinate problems (as discussed earlier) with little opportunity to develop system planning skills.

For example, traditional learning in physics covers predictive modelling, i.e. mathematical representations that can predict behaviour of physical systems. Predictive models are always approximations and it is often very important that the model adequately represents the real behaviour of what is being modelled – see, for example, Box 3.

Traditional learning tends to lead to a mindset that the use of science is determinate, i.e. that it leads to outcomes that can be accepted on the basis of logic alone: where the answer is either true or it is false. In system planning, most processes are not determinate: there are no 'correct' answers and judgement is needed. Box 3 describes a situation of this type where the predictive model should have been validated against the requirements. It is very important to learn to be reflective about the suitability of models in use, i.e. to have experience of making judgements about models. Learning of this type should be incorporated into existing subjects.

Many learners have difficulty in accepting the uncertainties involved in making judgements: they prefer determinate situations where there is no ambiguity. While the use of science, in engineering and in medicine, for example, is of incalculable value, students need to learn (a) to work with the underlying uncertainties when they use science and (b) to operate successfully when science is not available for predicting behaviour.

System planning, as defined in this paper, is relevant to STEM situations and to situations that are not directly related to STEM and is therefore relevant to all learners.

University education

Some university courses have significant proportions of project work. For example:In architecture, 50% of the curriculum is design studio work; all engineering degrees involve design project work. Most university students undertake a individual 'final year project' but I think that it is fair to suggest that the proportion of project work across university curricula is low.

A strategic objective of all universities should be that students develop system planning skills via multidisciplinary project work. That objective can be addressed at a course level, at a faculty level and at a university wide level. Some universities, e.g. the University of Aalborg in Denmark, have a significant proportion of the curriculum devoted to 'project-based learning'. The Engineering Council require that degrees in engineering involve multidisciplinary design project work.

5. Conclusion

System planning, the methodical achievement of outcomes in situations of complex uncertainty, is in common use across the spectrum of human activities, but a large sector of the population does not seem to understand how it is done or why it is needed. This is a serious flaw because we all need to work together to address global and local threats to society and to the environment. The root of the problem lies in education that should be structured to help people to develop the underlying skills but we cannot wait for education to catch up on that. The need, for example, for people in government to adopt system planning methods now, is manifest.

I cannot think of a more worthwhile objective in society than to ensure that when people seek to make the future better than the present, they know how to go about it in a professional manner.

Box 3 The Sleipner Platform collapse

In 1991, the construction of a North Sea oil recovery platform was nearing completion in a Norwegian fjord. Following a loud bang, the structure sank to the bottom of the fjord. The designers had, for the first time, used a 3D predictive model of the whole structure. The root cause of the failure was identified as a simple fault in the specification of the model. A simple back-of-an-envelope calculation (right) would have identified the error. There were no injuries or deaths but the cost of the failure was of the order of $700m