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The Future of Engineering

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Abstract

Technology is an increasingly important component of our existence and a determining factor in the evolution of society. Engineers are main drivers of both the development and application of technology, but is the engineering profession reflecting the rate at which both the nature of the work and the requirements on the education required to support it are changing? This article examines a limited aspect of this question in the form of a scenario, and points to some likely consequences for the work identified as engineering in the next couple of decades.

Introduction

It does not require a profound analysis to recognise that technology is a major driver of change in our society – changes to how we live, to how we work, to how we communicate with one another, and generally to how we experience the world around us. It is also easy to see that the rate of change is accelerating, and this has raised the question in many quarters as to the extent to which we, as a society, are currently controlling and responding to this change and, in a more extreme formulation of this question, as to the extent to which we are even *able* to do so (e.g. Ellul 1980). The Forum focused on one particular aspect of this issue, that of the future of work, both because of its obvious importance to society through its impact on the economy and the structure of society, but also because it is an area where the process of change has been very visible and well documented for quite some time.

The main features of this process – the changing demand for particular skills, the need for retraining and occupational flexibility, the shorter working hours, and generally the decreasing importance of paid work as the focus of life – are recognised, but are we also responding proactively to them, or are we simply trying to minimise the damage after the fact? In the following brief article we consider this question as it relates to one profession – engineering – which is at the centre of the change process, as it is largely engineers that develop the applications of technology that society experiences.

Technology, Engineers, and Industry

Central to an understanding of the work engineers perform and of how it is changing is a clear understanding of the concept of "technology". Reflecting the ubiquitousness of technological artefacts in a modern society, "technology" is a word that is used very frequently, but mostly in a general and imprecise manner. This was discussed in some detail in a recent discourse in this Journal (Aslaksen 2015), so here we simply recall that by "technology" we shall understand the resources engineers employ in creating applications that meet real or perceived needs of society; i.e. in performing engineering. Those resources can be conveniently divided into two groups: knowledge-based contained in textbooks, articles, standards, and also in the minds of experienced engineers, and the resource-base consisting of all the standard construction elements, from a standard bolt to a microprocessor, without which creating any application would be practically impossible.

In the process of creating new applications, engineers continually look for better ways of achieving the desired results and thus create new technology - it is this dynamic that drives the exponential increase in technology. A result of the continuous transformation of technology, as well as the current exponential increase in volume, is that, in the sense of understanding, maintaining, and being competent in using, various actors relate to different parts of technology, as illustrated in Fig. 1.

The *technical workforce* includes technologists, technicians, drafters, and trades persons; all persons that require access to the combined knowledge and resource bases, that is, technology. This structuring is defined formally, and to a large extent also in practice, by education and training, but experience and individual interest and aptitude can result in a significant blurring of the boundaries. For the present, we shall define an engineer as someone with a degree from an accredited four-year university course and meeting certain requirements for Continuing Professional Education (CPE). Engineers are the practitioners of the professional process of engineering, and the engineering disciplines, such as civil, chemical, electrical, and mechanical engineering, are distinguished by the subdivision of the resource and knowledge bases reflected in their education.

From one engineering project to the other, the ratio of creating new technology to applying existing technology varies greatly, but on the average the application of existing technology dominates by far, and it is useful to distinguish two groups of engineering projects:

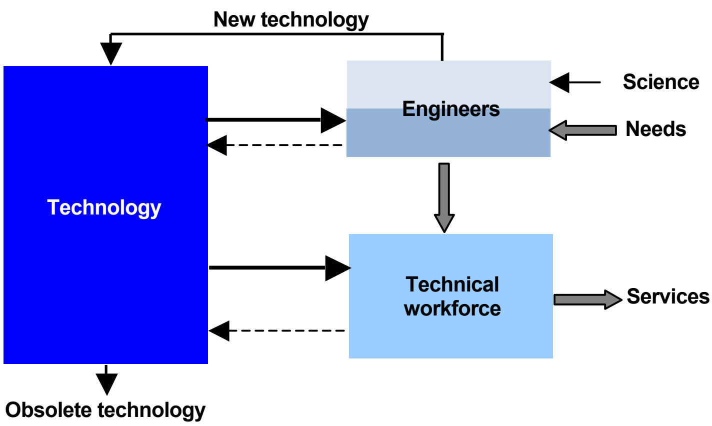

Figure 1: The interaction with technology by engineers and the technical workforce. The dotted arrows indicate that all engineering projects provide some input to technology in the form of experience, and the subdivision of the engineers illustrates the two types of engineering projects (see below).

- those that utilize the existing technology to meet a need expressed by all or a part of society; and
- those that are aimed at developing new technology.

Or, in other words, projects in the first group *apply* technology in order to meet requirements imposed by entities or people who are generally not engineers, and it is these stakeholders that are the judges of project success; whereas projects in the second group *develop* technology, often using that part of the knowledge base that is provided by science, but sometimes also based on heuristics or arising from trial-and-error, and their success is judged generally by other engineers. Let us agree to call these two groups of engineering projects *application projects* and *development projects*, respectively.

There is not a sharp boundary between these two groups, and there will be many projects that contain sub-projects of both types. In any case, every application project also leads to an increase in technology, if by nothing else than simply by acting as an example for later projects, as was indicated in Fig. 1. The usefulness of this grouping and the distinctiveness of the two groups was discussed in (Aslaksen 2012); in particular, as the group of application projects is very much greater in number and direct importance to society than the development group, it allows us, by focusing in the following exclusively on the former group, to make some general statements.

The Problematique

The suite of problems facing the engineering profession with regard to the future of work – the *problematique*, to use an expression introduced by Warfield (Warfield 2006) – is dominated by two issues, and the first of these is evident in Fig. 1. In that figure, the content of technology is in constant flux, with new technology entering at the top, and obsolete technology being discarded at the bottom. A corollary to this downward movement is the increasing degree of standardisation; what is leading edge technology today is embedded in a standard ten years from now.

The right-hand side of the Figure shows the stratification of the workforce, and it remains unchanged. The implication of this is that engineers should not be associated with the actual content of the technology but with a level of technology. The content of the technology engineers work on today should be handled by technologists in five or ten years.

The second issue is the influence of IT and the role of software. Software applications are relieving engineers of more and more of the time-consuming drudgery of detailed calculations and are allowing more sophisticated and cost-effective designs. And work at the lower end of the technical workforce, such as drafting, is being increasingly automated, in analogy to how machine code is automatically generated from source code. However, while computers and software will have a very significant effect on the future of engineering work, there is an aspect of this that is often overlooked, and to highlight this, we need to make a brief digression.

A Brief Historical Digression

The fundamental issue is that engineering, as a profession, has not been able to develop at the same rate as technology and its applications; in responding to the demands of industry, engineering has become a victim of its own success. This was discussed in a previous publication (Aslaksen 2013) by considering the environment in which engineering takes place. This environment, which was called *the engineering paradigm* on account of its similarity, as far as its influence on the profession is concerned, with the scientific paradigm introduced by Thomas Kuhn (Kuhn 1996), consists of a number of components:

- The technology, consisting of the knowledge and resource bases and the associated internal structure of the profession;
- the relationships to the other participants in the technical workforce, such as technicians and technologists, drafters, machine operators and trades personnel;
- the relationships to non-technical participants in engineering projects, such as business, finance, and marketing personnel; and
- the relationships to society.

All of these components underwent rapid change in the eighteenth and nineteenth centuries, and while this change had a different character and extent in different parts of the world, it resulted in creating, particularly in continental Europe, a profession on a par with science, medicine, and law. This *vertical structuring* of the technical workforce is illustrated in Fig. 2, where the vertical axis is intended to be a qualitative indication of the intellectual content of the activities involved, or what we might call engineering's *value-creating potential.*

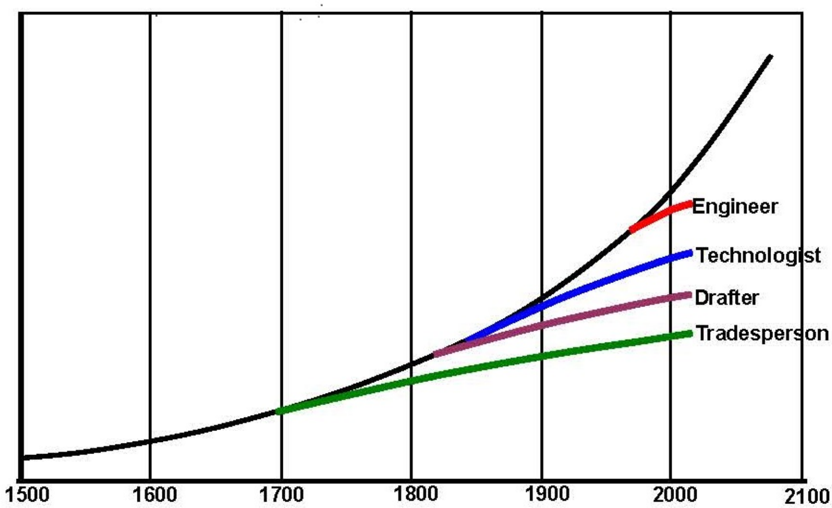

Figure 2: The development over the last six hundred years of one aspect of the engineering paradigm: the structuring of the technical activities within engineering projects by intellectual content (the vertical axis is intended as a qualitative indication only) (from Aslaksen 2013).

If we, for a moment, consider the field of technical activity to be described by two coordinates, type (civil, electrical, mechanical, etc.) and intellectual level (tradesman, technologist, engineer), then the enormous expansion of that field has been handled by increasing the number of types, i.e. increasing specialisation, but there has not been an increase in the number of levels. This *horizontal structuring*, as indicated in Fig. 3, brought with it its own problems, in the form of inter-disciplinary communications barriers and a narrow, stove-piped approach to projects. But, more significantly, it has not been complemented by a further vertical structuring; the *role* of engineers within the technical workforce is essentially the same as it was a century ago.

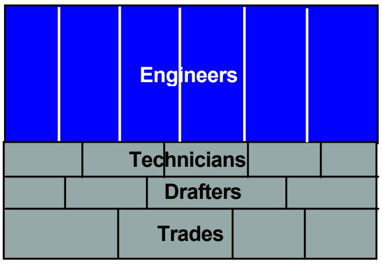

Figure 3: The horizontal structuring of engineering into disciplines.

This leads us now to the aspect of computing and software mentioned above, and it is best illustrated by a comparison with what happened as machine tools were introduced. For example, when engineers invented the lathe, it did not take long before a specialised class of operators, the turners and fitters, arose, and when sophisticated numerically-controlled tools were developed by engineers, specialised programmers and operators emerged; engineers did not have to operate the tools they invented. But in the case of engineering software applications we have not yet been able to make this transition, and a considerable amount of engineering time is spent on learning how to operate software applications (which can be similar to learning a new language) and then applying them. This process, while resulting in an increase in productivity, invariably leads to increased standardisation and to a consequent lack of creativity, but also involves a significant investment in maintenance due to the frequent upgrades and, above all, does not really require an academic education.

A Possible Scenario

As has been pointed out in another contribution to this volume of the Journal (Vanclay 2016), predicting the future development and consequences of technology is very difficult, if not futile, and a much better approach is to construct a number of possible future scenarios, estimate their probabilities, analyse their consequences, and then selecting the most desirable one as the basis for planning. Here we present one such scenario for the future of engineering.

Due to the exponential increase in the technology and the similar increase in the interface between technology and society, the requirements on the education, training, and social integration of engineers reach a point where the current paradigm breaks down. Not a breakdown in the Kuhnian sense, but in the sense of a glaring deficiency in cost-effectiveness. If engineers are to be able to meet these requirements, they need to rise above the largely routine part of the activity to be able to focus more on creativity and the concerns of society, and one or more new levels should be created within the technical workforce to meet the needs of industry for the application of the standardised part of technology, as illustrated in Fig. 4. The driving force behind the proposed restructuring would have to be the engineering education sector and the professional skills of academia, as only a formal, vertical structuring will yield the desired results. The present approach of adding a few non-technical subjects to the engineering curriculum is not effective. First of all, because one cannot just add material to a degree program with fixed duration, the technical part of the curriculum is necessarily reduced in scope, often without explicitly acknowledging the effect this will have. But more importantly, because what is needed is a fundamental differentiation in the approach to knowledge. Reduced to a minimum, one could express the difference as being between understanding and competence, or perhaps between a professional and a worker. Like the transformation of craftsmen to workers in the industrial revolution, the role of engineers has changed from the shining knights spearheading society's way into a glorious future to invisible intellectual labourers, anonymously providing the fuel for industry's relentless drive to transform society into a consumer society, with Growth as the Holy Grail and with marketing and advertising as its handmaidens. This was already discussed in Veblen (1921), and again in Noble (1977).

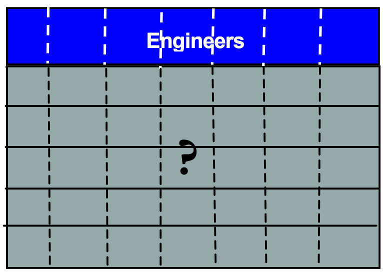

Figure 4: Vertical restructuring of the technical workforce, relieving engineers of the largely standardised parts of their current workload.

At present, engineering education and the various certifying and accrediting bodies are focused very much on competence, on being skilled in applying engineering knowledge to meeting the needs of industry. What is needed is to separate the engineering program from the practical applications program, so that the program provides the students with an appreciation of the structure and functioning of society as it relates to possible interfaces with engineering, and prepares and motivates them to take a critical and proactive role in increasing society's appreciation of the options and consequences the application of technology offers. It is a role somewhat analogous to that of journalists: working as employees within an organisational environment, while maintaining both close relationships with society and their professional independence and ability to pursue the truth.

The engineering program might have a total duration of five-and-a-half years, with the last half year dedicated to completing a small research project, and would not be strictly discipline-based. While much of the basic technical knowledge, at least in the first two years, would be the same as in the current BEng program, it would emphasize the place of the knowledge within a broader, somewhat more abstract framework, and introduce the system concept as an essential aspect of engineering. Following the first two years, about half of the engineering subjects would be common (mandatory) and half discipline-based (selected); they would be complemented by a common set of subjects in sociology, law, economics, and philosophy, presented with a rigour appropriate to engineering students, and always from the perspective of their relationships to engineering. The importance and complexity of the relationship between engineering and society warrants the same rigour of study and research applied otherwise in engineering; what is required is the application of the engineering methodology to social issues rather than for engineers to dabble in sociology.

The proposed restructuring would, of course, have a significant impact on the education and training of the technical work force. The number of engineering graduates per year required by industry would be only a fraction of the current number of combined MEng and BEng graduates, and the number of institutions offering this degree would be correspondingly reduced. The qualification for the level below engineer would formalise what is already the case for something like three-quarters of BEng graduates who go into fairly routine positions in industry, and in doing so, would allow a sharper focus on the needs of industry and make both education and employment more effective.

Our economic system is based on growth; initially driven by the desire for a secure lifestyle, but once this and the capital associated with the security has been achieved, growth is driven by the pressure to provide opportunities for investing this capital and receiving a return on it, as the earning value of capital (in addition to the earning value of labour) is the basic tenet of capitalism. And that is what industry provides; each project can be viewed as basically an investment opportunity. This exponential increase in the size of the economy can, of course, not continue indefinitely. However, in the medium term, say, the next few decades, we should expect continued and increasing economic growth and an increasing technical content of the new services, so that engineering will account for a rapidly increasing fraction of the GDP. But under the restructuring of both the work and the technical workforce proposed in this scenario, together with the more effective use of computers, the demand for engineers will decline significantly.

References

Aslaksen, E.W, 2012, *An Engineer's Approach to the Philosophy of Engineering*, Abstracts of fPET-2012, the forum on Philosophy, Engineering and Technology, hosted by the University of the Chinese Academy of Sciences in Beijing, November 2-4, 2012. Full paper available at www.gumbooya.com

-, 2013, *The Engineering Paradigm*, Int'l J. of Engineering Studies, Vol. 5, No. 2, pp. 129-154.

-, 2015, *The Relationship Between Engineers and Society: is it currently fulfilling its potential?*, Journal and Proceedings of the Royal Society of New South Wales, vol. 148, nos. 455 & 456, pp. 28-43.

Ellul, J, 1980, *The Technological System*, The Continuum Publishing Corp.

Kuhn, T.S, 1996, *The Structure of Scientific Revolutions*, 3rd ed, Univ. of Chicago Press.

Noble, D.F, 1977, *America by design: science, technology, and the rise of corporate capitalism*, Alfred Knopf.

Vanclay, J.K, 2015, *The Future of Work: Pivotal Decisions for Society*, Journal and Proceedings of the Royal Society of New South Wales, vol. 150, nos. 457 & 458, pp. 154-158 (this volume).

Veblen, T, 1921, *The Captains of Industry and the Engineers*, p.61, in *The Engineers and the Price System*, B.W. Huebsch, Inc. New York.

Warfield, J.N, 2006, *An Introduction to Systems Science*, World Scientific Publishing Co. Pte Ltd, Singapore.

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