How engineering education can contribute to a revival from the economic downturn

Professor D. McKeag, School of Engineering, University of Ulster at Jordanstown, Shore Road, Newtownabbey, BT37 1QB. [D.McKeag@ulster.ac.uk].
Tel: +44 02890 268599. Fax: +44 02890 368580.

Abstract

The economic downturn is causing recession in the industrially developed nations of the western world. Historic analysis reveals this phenomenon to be nothing new but in fact cyclic, as periods of excess, financed by perceived wealth and fuelled by debt, are followed by a long period of readjustment. We are entering such a period of readjustment, and despite the best efforts of politicians to have us believe that the good times are just around the corner, the historical evidence suggests we are in for a ten-year period of "readjustment". The historical evidence also indicates that technological innovation driven by engineers will be the means by which the industrial nations will emerge from the deep recession. Along the way the social order within nations will be redefined and there will be a new world order amongst nations. This paper outlines how the quality of engineering education can be improved to produce graduates who will be capable of creativity and innovation in the new social and world order, and who will help lead us out of recession. It also outlines some of the problems with the current systems, and how these problems can be addressed

Key Words: **e**ngineering; creativity; innovation; education, industry

1. INTRODUCTION

The worldwide economic downturn is affecting everyone on the planet. In a relative sense the worst affected countries are the industrialised nations. A casual analysis indicates that these nations have forsaken the basis on which wealth and prosperity was built in favour of easy financial gains. Ultimately wealth is created through trading. This trade may be based on fishing, farming, mineral exploitation or trade in manufactured goods. Unfortunately the industrialised nations, with few exceptions, have focussed in recent years on financial services, property, and easy credit as a means of bolstering GDP leading to an unsustainable bubble that pragmatic engineers realised had to burst. The folly of the current generation has effectively led to countries such as the UK being bankrupt [23], with the creation of debts that will have to be paid by our children and grandchildren. Perhaps most galling of all to those operating in the "real" economy is that bankers, who are largely responsible for the economic demise of the economies of industrialised nations, are being bailed out by taxpayers.

It is inevitable that when the fall out from the economic downturn has settled a new world order will emerge, both economically and politically [21]. We need to focus on what the new world order will be, and how we can once more generate real wealth and prosper in the new situation. A simple view is that the nineteenth century saw the introduction of mechanisation of manual skills leading to growth in industrial output. The twentieth century saw automation allied to the introduction of computers lead to fast new product development and the growth of the consumer market. More recently digital information and communication systems have provided new and radical user experiences that could not have been envisaged only a few years ago. It is reasonable to suggest that those societies and nations that are to grow and prosper in the future will base new product, process and systems innovation on what has been achieved, and will continue to amaze the customer and consumer with what can be achieved through application of science, technology and creative design, aptly supported by service industries such as the banking sector. The basis of this progress will be, as in the past, clever engineers.

Clever engineers will be those who on graduation are competent engineering scientists, are abreast of the latest scientific discoveries, manufacturing and materials technology, who are creative and see opportunity for technological and design innovation, and have the management skills to enable their ideas become reality. These engineers will have to be the cream of the output from our secondary education systems, and if they are to be attracted into engineering the financial rewards will have to be apparent at the point of entry to third level education. Because of the rapidly changing pace of scientific discovery, technological and design innovation, the clever engineers of the future will need on-going personal development.

This paper will outline how we learn, provide an account of some of the problems faced by society and engineering, and based on the evidence suggest the sort of engineering education needed if we are to be creative and use innovation as our way out of the recession.

2. HOW WE LEARN

If we are to produce clever engineers then it follows that we should know and understand how to teach, train and develop young people so the objective and be achieved. Edgar Dale [1] was one of the original researchers in the field of visual learning, and generated a Cone of Experience or Cone of Learning that has influenced many teachers to this day on what constitutes sound education and training. There are many variations of Dale's Cone of Experience [2] but perhaps the most widely known is that reproduced in Figure 1. From Will Thalheimers research based commentary on learning [2] it becomes apparent that the origin of this variant of Dale's Cone of Experience is vague, and the included data probably misleading. Dale's original Cone does not contain figures but most of the subsequent variants do. Further research reveals additional data related to learning experiences and of generally dubious or unknown origin. For example [3]:

How we learn:

1% through taste
2% through touch
3% through smell
11% through hearing
83" through sight

An apparent contrast between these figures and those referred in [2] is that there is no room for learning through doing. In the variants of Dale's Cone taste, touch and smell do not get mentioned. It could be argued that taste, touch and smell are part of the experience of learning through doing.

Business references to communication have interesting data on the effectiveness of spoken communication, they tend to agree on Albert Mehrabian's communication model [4] that:

7% of meaning is in the words that are spoken
38% of meaning is in the way the words are said
55% of meaning is in facial expression

The closely supportive breakdown for each component of communication [5] is:

7% of meaning is verbal
23% of meaning the way words are said
35% of meaning is in facial expression
35% of meaning is expression through bodily movement

A well researched CISCO publication [6] gives an academic perspective on multi-modal learning through media, as it can be argued that the many of the variants of Dale's cone were developed in support of multimedia learning. In this article there is an account of physiology and specifically to “the way our brains are wired” that “severely limits our capacity to learn”. For engineers a significant conclusion supported by scientific evidence is that thinking processes happen serially, and that multitasking causes delays in switching from one task to another. These delays (with inferred greater loss in efficiency) become more pronounced as tasks become more complex. Another interesting disclosure for engineers is that the CISCO article draws an analogy with brain memory and computer memory through the term “buffers”. Our memory is “dual-coded” with a buffer for storage of approximately seven verbal/text elements simultaneously, and a second buffer for storage of approximately four visual/spatial elements simultaneously. It follows that multitasking can cause cognitive overload. Another deduction for the engineer is that experience is only beneficial if the student pays attention to the sensory experiences, thus enabling these experiences can be held in long-term memory. “Since thinking and decision making invoke long term memory and require the central processor, which only works serially” it is reasonable to deduce that engineering students working with the complexities of modern day mathematics and science learn best when their mind is focussed on one task.

There is a great deal of debate surrounding the best ways to learn [7]. General terms used to describe modern learning are “holistic approach” and “learning through doing”. However the article does make a number of substantiated statements:

- There is evidence that deep immersion is required in a discipline before anything of novelty can be produced
- All evidence indicates that real competence only comes through extensive practice

The article goes on to state that the tendency is to cut out substance from subjects to the extent that students end up dumbed down without the tools to be creative. In terms of engineering education in the UK, this view is supported my many leading engineering academics [15]. The view that immersion and practice is required is supported in the CISCO article [6] where it is recorded that students develop expertise through deep understanding.

These findings are in agreement with the concept of associative thinking [8] which embraces five techniques as the source of new ideas: adoption (of a design from another discipline), technology transfer (from one discipline to another), combination of two or more existing ideas, analogy (frequently with nature) and chance. However it is the final technique of chance that is often overlooked by educators and it is the most important. Chance favours the prepared mind, and just as recorded in the preceding articles, deep immersion and deep understanding in a discipline is required before anything of novelty and value is likely to emerge.

In the context of invention [9], “act of insight” is the phase in the process where ideas are generated, and it is the concept of associative thinking that that is at the core of this phase in the process of invention. However invention on its own does not generate wealth, in fact invention costs money. It is the commercialisation of ideas that generate wealth and this is better known as innovation. It follows that invention is the first phase in the process of innovation [10]. Now the process of innovation of necessity embraces the process of design, which is the means by which ideas are translated in to plans to produce new products, systems or processes. It is at this point that the role of engineering, and in the context of this paper, the role of engineering education, becomes apparent in addressing the economic downturn.

We are in the business of producing clever engineers, and these should be competent engineering scientists who are abreast of the latest scientific discoveries and advances in manufacturing and materials technology. They will be creative and see opportunity for technological and design innovation, and have the management skills to enable their ideas become reality [14].

Design, which is the backbone of innovation, is resistant to definition, but it is possible to understand design by identification with objects, through development of key skills, through process and through participation in activity [11]. Engineering is a design profession, as an engineer is someone who designs and makes products (processes or systems). Innovation, which is the vehicle by which governments in the developed economies would have us emerge from the economic downturn, requires engineers.

Following from the above discussion it is possible to more clearly identify what constitutes a clever engineer. From [11] it is apparent that an engineer is a person who has key skills in drawing and modelling. However these key skills are of necessity abstract, and in the form of scientific formula, mathematical equations and data. The engineer must be computer literate, and be capable of representation of ideas and design concepts in an abstract way that is meaningless to all but fellow engineers, and even then perhaps only those in the same or an associated discipline. This means deep immersion in the engineering discipline and learning the mathematics and science necessary to produce these abstract models and verify them through computer simulation, proof of principle modelling, prototype evaluation and empirical assessment in service. In the modern world of increasing technical complexity and the multidisciplinary nature of new products, there is no "holistic" or experience base shortcut. The acquisition of the base knowledge necessary for abstract modelling must be personally learnt and honed to perfection through practice. At this base level learning is personal and the job for the lecturer or teacher is provide the knowledge in economic way possible for the student learn, understand, and gain competence in its manipulation. Research evidence [6, 12] clearly demonstrates that the best and most efficient way to learn the base knowledge is through non-interactive multimodal learning. This is clearly in disagreement with the modern learning techniques promoted in many schools and colleges [7]. However, whereas the finding in [6] is evidence based, it would appear that the teaching techniques cited in [7] are opinion based.

3. THE INDUSTRIAL AND SOCIETAL PERSPECTIVE

Article [7] and others like it address creativity, which can be defined as a goal directed human activity that results in novel or original work that is perceived to be of value to individuals or society [13]. It is already suggested in the introduction that engineers and engineering have been collectively responsible for the industrial revolution, and the subsequent technological innovations that are the basis of our modern industrialised society. A publication around the early 1970's (source lost in the passage of time but believed to be an ICL publication) put the explosion of knowledge into perspective by stating that "if we consider mankind as having one unit of knowledge up to the time of Christ, by 1500 we had two units of knowledge, by 1725 three units of knowledge, today the sum total of human knowledge is increasing by one unit every three years and the timeframe is decreasing". Basically this means there is an exponential growth in the sum total of human knowledge. It is possible to categorise this knowledge into scientific knowledge which is our understanding of the created environment, technology which is how we manipulate the created environment, and philosophy which is what is important to people. Clearly engineering transcends and embraces all three categories because our work is based on scientific knowledge, through technology we make products (processes or systems) and through design we harness our scientific and technological knowledge to create something that is of value to people. Clearly then it is the responsibility of engineers to harness the incomprehensible marvels of modern technology and produce products that people like, can use, feel safe with and want to possess. If this is the challenge to engineers then the challenge to those in engineering education is to produce graduates who have the knowledge, creativity and foresight to be genuinely innovative.

The real challenge for educators is how to train and encourage engineers to become creative and innovative. There is a perception that creativity is the domain of the arts, and in the context of design is predominantly associated with aesthetics, covering shape, form colour texture and pattern. In the domain of the industrial or craft designer no technological innovation is possible because there is no deep-rooted immersion in science and mathematics. It follows that abstract modelling is not possible, so innovation is limited to new arrangements based on existing technologies. In the industrial and fine craft design disciplines, creativity can be enhanced through use of concepts such as associative thinking referred to earlier. These design disciplines are largely visual, and the impact aesthetics has on the perceived quality and value of a product and the associations it invokes should not be underestimated. However real progress in an industrialised society is dependant on technological innovation and associated creativity and this is the domain of engineers [24].

It has been demonstrated that the best way to get engineers to know and understand creativity and innovation is through a four-phase approach covering observation, key skills, process and activity [14]. The argument for this approach is that creativity and innovation are non-verbal topics and as such cannot be learnt, but rather understood through this approach. Observation helps identify what is innovative in ones own discipline, process is (generally) presented as a sequence of activities that takes the engineer or other design profession from need, want or opportunity through to the commercial solution, practice is the multidisciplinary activity that leads to sound knowledge and understanding through doing, and key [usually abstract] skills are developed through learning by doing. This learning is inevitably multi-modal team based activity requiring innovative solutions to real problems [14]. Final year engineering students participating in semi-structured close to market innovation activity are observed to learn at an accelerated pace, and are very well prepared for meaningful entry into the employment market on graduation.

The value of multi-modal learning is supported by academic papers on the subject [6, 12]. In the academic research examining the value of multi-modal learning, it has been shown that interactive multi-modal learning increases higher order skills by 32% over what can be achieved by non-interactive single modal learning. However evidence from the same source supports non-interactive multi-modal learning of an individual nature in the more formative years of a programme. In the early years the emphasis should be on learning verbal subjects such as mathematics and science, which provide a platform for subsequent creative and innovative work in the final years of courses.

4. IDENTIFYING THE PROBLEMS IN THE CONTEXT OF ENGINEERING EDUCATION

We are living in times of economic uncertainty for the industrialised nations. Published figures show that all nations are suffering as a result of the global recession, but examination of the economies of the G20 group of nations, from figures published in March 2009, demonstrates an interesting statistic (table 1). The "mature" economies such as those in the UK, USA, France, Germany, Italy etc are all showing a negative rate of growth of around –2%. By contrast the economies of the "developing" nations such as India, China and Indonesia are showing growth rates of around +5%. The difference is that the "mature" economies amongst the industrialised nations have largely forsaken the basis on which their wealth was built, and instead have focussed in recent years on financial services, property, and easy credit as a means of bolstering GDP, leading to an unsustainable bubble that pragmatic engineers (supported by historical analysis) realised had to burst. The developing industrialised nations by contrast have based their wealth on the growth of manufacturing industry, and the mature economies have been only too keen to offload to these nations much of their manufacturing activity on the basis of low cost. In consequence the mature industrialised economies are shrinking and the newly industrialised economies are growing. It is inevitable that a new world order will emerge as a consequence of the global recession. Based on analysis of the past growth in economies as a result of the industrial revolution, and subsequent industries based on mechanisation, automation, computerisation, and growth in digital information and communication systems, it can be confidently predicted what that the new world order will be. It will be led by those with a strong economy based on a significant manufacturing sector, and with significant investment in science and technology, leading to new products, processes and systems that give users new experiences and lead to new opportunities for growth, profitability and expansion in the manufacturing sector.

The argument has been made for clever engineers, but compare that with what is happening in our third level educational sector. There is a drive by Governments for more graduates to drive and sustain the "knowledge" economy and this has created many columns of debate and discussion in reputable newspapers in recent years [16, 17]. Before the current economic woes were upon the industrial nations, many were expressing the need for investment in research, development and innovation as a means of maintaining, sustaining and developing our manufacturing base, and by implication this was recognised as the basis of wealth in our society. In the UK this was interpreted as the need to get 50% of our young people with third level qualifications. The problem here is that in the UK university education has traditionally been for an academic elite, people who were prepared to compete for entrance to university, and once admitted were prepared to work to maintain their place in the university and to achieve their qualification. In the past standards were rigorously applied and failure was the consequence of inadequate ability and/or insufficient work ethic. With the need to admit more students and achieve numbers targets upon graduation, new "vocational" university courses have been written and academic standards adjusted to cater for the intellectual ability and strength of commitment of the new intake. The result is watered down degrees [15] that fail to meet the needs of the knowledge economy.

One consequence of the larger intake to universities is that fewer academically bright students are opting for an engineering education, and this is borne out by recent statistics relating to other professions [20]. Clearly there are a number of issues that need to be addressed if the industrialised nations are to grow and prosper as in the past. From the discussion and analysis presented to date in this paper some concerns, problems and needs can be identified and expressed thus:

1. Stop haemorrhaging manufacturing jobs to developing countries
2. Invest in research and development that will lead to innovation in products, processes and systems
3. Ensure that engineering is a challenging and worthwhile career for our best second level students
4. Offer engineering degrees that require immersion in science and mathematics as the basis for creativity and innovation

5. Design engineering degree programmes that focus on individual learning in the early years of the degree programme and become more team based and industrially relevant in the final years
6. Use multi-modal teaching throughout the degree programme
7. In the final year introduce innovation as a creativity activity based on a firm foundation of science and mathematics, and work with research focussed companies on the solution of real problems

5. CONCLUSIONS AND RECOMMENTATIONS

The haemorrhaging of manufacturing jobs can be addressed through investment in automation, mechanisation and use of computer technology. However in the short term it is more likely to be addressed through the increase in costs of the developing industrial nations, the decrease in costs in the developed industrial nations due partially to wage restraint coupled with a reduction in the value of the currencies of these countries.

Analysis based on Kondratief [21] and Schumpeter [22] long wave cycles suggests that we are in for a long period of recession, estimated at around ten years. According to Kondratief analysis [21] the waves are caused by periods of excess financed by perceived wealth and fuelled by debt, followed by a long period of readjustment. During the trough there is much consolidation and investment in innovation and it is this sustained activity over many years that once again produces growth and prosperity. Appropriate government intervention should be able to cushion the economic downturn and support the investment necessary for recovery, and this investment will need to focus on the manufacturing sector. An observation would be that the governments of the mature industrial economies are more concerned with cushioning the impact of the recession on those responsible for creating the economic bubble, and less so on providing support for those who are suffering as a consequence of it. In addition there would appear to be relatively little support for those in the manufacturing sector who will ultimately get us out of the recession.

Within the developing industrial economies engineering is seen as a worthwhile career [16] with India producing more graduates than all of Europe combined. In India there are 350,000 engineering graduates every year and competition for a place in a school of engineering is fierce. By contrast, in places like the UK, the lure of high incomes in the service industries as typified by the insurance and banking sectors, and the returns offered by financial speculation in areas like the building sector, have drawn many school children to opt for careers in these areas, and follow an educational route that will help them realise their ambition. The consequence is that there is little competition for places in engineering courses in the UK (and by inference in other developed industrial economies), entry standards are lowered to achieve the target entry (if at all), and engineering schools and departments in universities are closing. Increasingly research and development laboratories are full of graduates from the developing industrial nations such as India and China [17], and as reported, they are starting to go back home as more opportunities become available. Our wealth-generating sector has got to hope that the recession will lead to a re-evaluation of career prospects for school children, and encourage more to take up science and mathematics in school, and progress to a career in engineering. It should also be hoped that our governments would through intervention, stimulate education to provide career paths in this direction whilst concurrently ensuring that world class engineering academic standards are achieved and maintained in engineering disciplines.

The earlier debate on education clearly demonstrates that if creativity and innovation is to be achieved amongst engineering graduates, then the fundamentals of engineering, namely mathematics and engineering science, must be the bedrock on which good engineering courses are built. Research shows that multi-modal teaching is required throughout the curriculum, and in the context of engineering this means investment in laboratory and workshop facilities, and providing undergraduates with the opportunity to interact with the equipment and gain first hand experience. Many engineering lectures can be boring to undergraduates because of the delivery skills of the lecturer. In this respect lecturers should learn from what has been found through research in business schools [4, 5], and in conveying meaning put much greater emphasis on vocal modulation, facial expression and body movement. Engineering lecturers may need some training in drama and the performing arts if this goal is to be achieved. In these days of competition from all sorts of media and the celebrity culture it is surely time to offer “Oscars” to engineering lecturers! In terms of introducing creativity to engineering courses, much of the creativity introduced does depend on drama [14, 24].

In the formative years of the engineering degree, when the groundwork for creativity and innovation is being laid through personal learning, research shows that the best way to learn is through individual activity. In the later years of an engineering course emphasis should shift to peer (group) learning with a degree of individual interaction with resources. In this final stage it is important to get students as closely as possible integrated with creativity and innovation in the workplace [14]. This means working with research active industry and through constrained learning based on the solution of real engineering problems, guiding students through the whole process of innovation, and supporting them in the acquisition of new knowledge and skills. Through this multi-nodal, multidisciplinary role play, engineering students will graduate with a clear understanding of innovation, what it actually is, and how they can make an immediate contribution to the financial success of their employer and the economy of the country.

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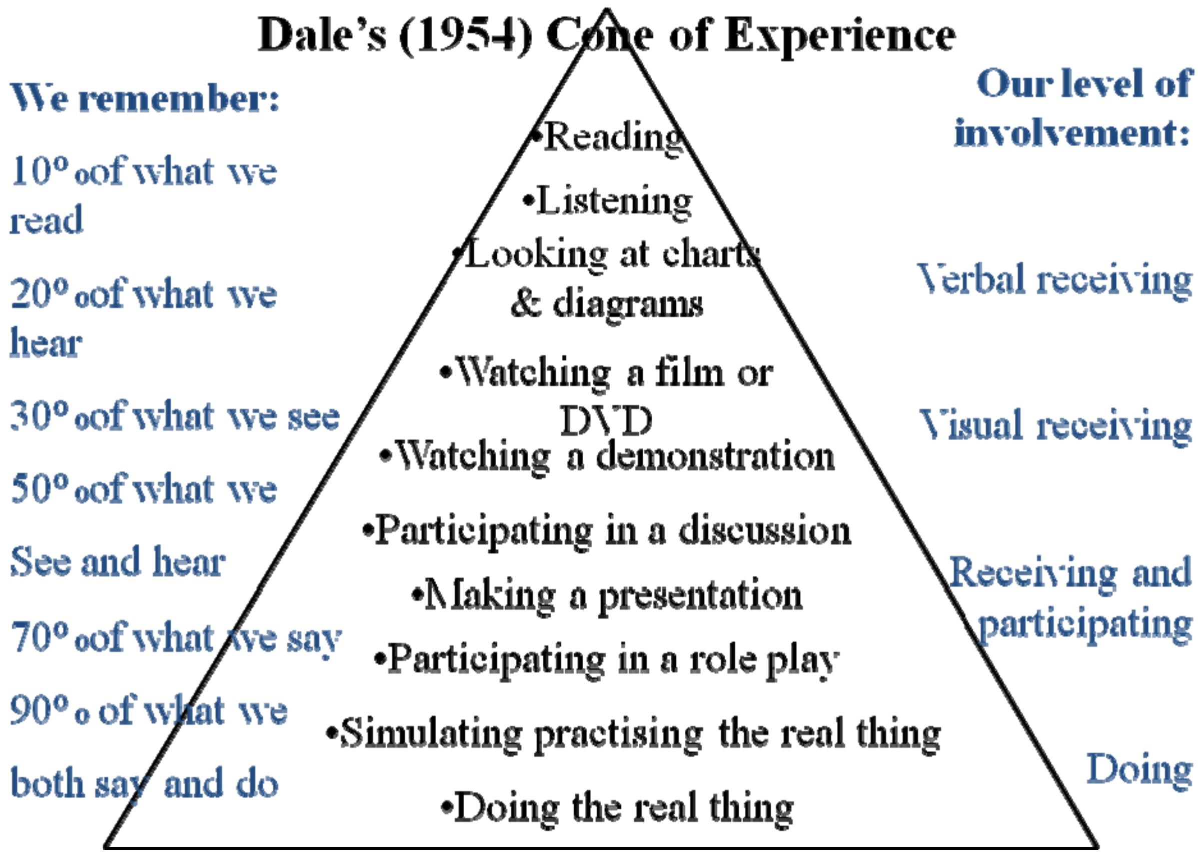

Figure 1: Dale's [1954] Cone of Experience

Country	**Projected change In GDP over the Next year**
China	6.7
India	5.1
Indonesia	3.5
Brazil	1.8
South Africa	1.3
Saudi Arabia	0.8
Argentina	0
Australia	-0.2
Mexico	-0.3
Russia	-0.7
Canada	-1.2
Turkey	-1.5
US	-1.6
France	-1.9
Euro zone	-2
Italy	-2.1
Germany	-2.5
Japan	-2.6
UK	-2.8
South Korea	-4

Table 1: Projected Changes in G20 GDP for 2009, Source: IMF