ENGINEERING DESIGN EDUCATION: SKIN DEEP OR IS THERE A NEED FOR BODY?

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ABSTRACT

An engineering infrastructure through manufacturing industry is an important means of generating income capable of considerably benefiting national economies. From a general perspective engineering enhances and supports all of our daily lives through significant contributions to medicine, transport, energy generation, water and food supply, communications and entertainment. In fact there is little we do each day that is not supported or aided by the involvement of an engineering input. At the heart of engineering is our ability to design; to anticipate, perceive and solve problems whether purely technical or human centred but mainly a combination of both. Although the successful design of an artefact may start with divergent thinking appropriate to an open approach the final outcome cannot be achieved without the convergent thinking of an analytical mind.

Based upon the authors experiences in industry and higher education the paper discusses the problems associated with teaching the next generation of engineering designers so they are able to confidently and reliably meet and satisfy an ever-growing demand for innovative, high quality products and services. To achieve this it is argued that taught primary cognitive skills should include competence in core knowledge, effective problem solving skills, and an ability to think critically, creatively and apply sound engineering judgement. In addition the effective engineering designer needs social and interpersonal skills in order to progress the product through manufacture to market. A generalized model is proposed that may be used as a basis for structuring future engineering design courses within higher educational institutions.

Keywords: Engineering design, higher education, technical competence, transferrable skills, course structure

1 INTRODUCTION

A strong education system goes "hand in hand" with a vibrant science and engineering industry. However, the demand for graduate engineers is exceeding supply and this demand is pervasive across all sectors of the economy [1]. Whilst a deficit of around 60,000 engineering graduates exists in the UK some 26% of engineering graduates do not pursue careers in engineering or technical professions. More worrying is that 85% of all engineering and science postgraduates in our universities come from outside the UK [2]. As well poor availability engineering companies are also concerned about the type of graduate engineers they need to recruit. Employability skills are the most important factor taken into account when businesses recruit engineering graduates; hence universities need to increase the business relevance of engineering courses [3]. Today, companies increasingly require engineers who can design and deliver to customers not just products, but complete solutions; many involving complex integrated systems. Increasingly, companies also demand the ability to work in globally distributed teams across different time zones and cultures. To address this problem a change in undergraduate engineering education is urgently needed to ensure graduates remain equipped for the new and complex challenges of the 21st century [4]. A meeting a few years ago between Chancellors of Western and Chinese universities chosen as potential world class research establishments provided an important insight. Among the Western representatives was a Renaissance Scholar, an economist, a political scientist, a linguist, a mechanical engineer and a lawyer. The Chinese delegation consisted of six physicists and an engineer. There is a clear message here and we need to learn and to learn fast.

Employers require engineering graduates with good transferrable skills as well as sound and appropriate technical subject capabilities. Experience indicates most engineering employers actually consider transferrable skills as important as technical ability asserting that such graduates integrate more rapidly into productive employment. Engineering courses must motivate students to become good engineers as well as provide students with the range of knowledge and innovative problem-solving skills necessary to work effectively in a global industry. Providing an integrated design theme many engineering design courses also provide key transferrable skills development. Students maybe driven by passion, curiosity, a need to succeed and bring dreams to reality - all of which should be encouraged. This paper outlines how technical ability and transferrable skills can simultaneously be developed in engineering students by a course structure that draws parallels with best practice in industry whilst encouraging innovation and creativity.

2 DEFINING THE SCOPE OF ENGINEERING DESIGN

What is design in the context of engineering? Design has different meanings depending upon what it is being related to and who is making the consideration. Although a single definition of design may be difficult to arrive at all design is human centred and pragmatic. Design has been described as the link between creativity and innovation whilst at least considering aspects of the full life cycle [5]. It is a process that enables ideas to become practical and desirable by customers i.e. creativity deployed to a specific end. The most distinctive attribute of all design is that it makes ideas tangible, taking abstract thoughts and inspirations and turning them into real objects that can be seen, felt and used for a specified purpose. Design decisions impact upon all our lives whether it is at home, at work, travelling from one place to another, or simply enjoying a period of relaxation. Given the diversity of what we design it is not surprising we find understanding design specifically somewhat ambiguous and therefore teaching the subject fraught with difficulty.

Design is often considered solely as being related to an object's appearance without due consideration to its workings or how it was manufactured. Engineering designers, unlike artists and others concerned purely with shape, form and colour, cannot simply follow their creative impulses. The process of engineering design usually commences by clearly defining objectives and establishing criteria which need to be fulfilled. Put simply, engineering design may be viewed as an activity that translates an idea into a communication to achieve, i.e. a specification for manufacture [6]. Engineering designers work within well-defined constraints entailing a large number of considerations, some or all of which may not be known or understood at the outset. Consider President John F. Kennedy's announcement on May 25th 1961 when he declared the ambitious goal of "sending man safely to the moon before the end of the decade". As well as declaring a very tight time scale a considerable understanding, at the time, of both known and unknown technical and scientific aspects was required. There was also a need to consider aesthetics, a range of functionality, economics, biological requirements and constraints, and if that was not enough there were socio-political aspects ever present. Design fields outside engineering may find this definition extremely demanding and highly restrictive.

Whatever the goals set for a design the process is conducted with non-perfect models, incomplete information and even ambiguous objectives. A major challenge confronting designers is that as the number of variables and interactions grows, and it generally does, the system stretches beyond the reasonable capabilities of any single designer to gain a full and simultaneous grasp of all details involved. Good engineering designers are good estimators; their experience and knowledge allows them to make a judgement on what is suitable for a given situation. They are able to effectively determine the relative size of physical parameters and accurately determine those that are not important. Engineering design students are generally considered to be in the early stages of learning this and hence tend to be limited in their ability to predict values and outcomes.

3 TEACHING ENGINEERING DESIGN

Arrival at a satisfactory definition for design presents many problems which, is one reason why teaching engineering design in conventional educational environments is difficult. Some would say the task is impossible to achieve in a full and meaningful way given the students' limited experience and ability to "feel" what is achievable and what is not. In addition the level of understanding required in science and technology has become extremely complex and now requires specialisation in several areas if designs are to benefit from new materials, technologies and processes. As discussed previously to successfully solve engineering design problems not only requires technical knowledge and understanding but also proficiency in transferrable skills [3, 4]. As a result many designs today are achieved through multidisciplinary design teams, many globally based. As a result design education should be more sensitive to a multidisciplinary, team based approach difficult as it may be to achieve.

The successful integration of technical ability and transferable skills is ensured through a holistic approach to curriculum design. A generalised model for the structure of possible future engineering design courses that encapsulates the skills needed for engineering design graduates, as outlined in the previous section, is proposed in Figure 1. The model comprises three different skills domains with technical competence at the core bounded by key transferrable skills and linked by cognitive ability. The structure implies strategic application of the skill factors with no hierarchy between the domains. The role of the different skill factors and their repercussion on engineering design education are explained through the narrative of industrial practice A.

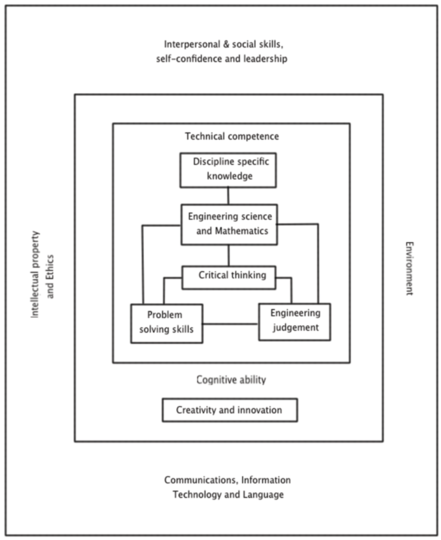

Figure 1. A generalised model for the structure of future engineering design courses

3.1 Putting the design process in perspective

Design is often taught as being a rational and sequential process stepping from one set of considerations to the next down a progressive path [6]. However, a study of industrial history will show this has not always been the case. Design has often been a rather chaotic process driven primarily by a domineering and ambitious individual who was not always open to consultation or consensus. This is the antithesis of the Total Design approach often used as a basis for teaching design today. It was, however, the process by which many very successful designs were achieved. As our knowledge grew, specialisation developed and areas of work became compartmentalised and defended with rigid boundaries defining major activities. Work taken in at one end of a company was explored, developed and modified unilaterally and then finally passed on with little if any consideration of the constrain it may place upon successive activities along the design to manufacture path. The role of a designer was to balance all considerations and make decisions to arrive at information and details that would enable final and successful manufacture of the product. This was a closed approach and limited communications leading to what became known as an “over the wall” system of design and manufacture. It led to repeat modification of the design and manufacture process resulting in extended lead times and manufacturing costs. The inevitable outcome was late delivery times, frustrated and unhappy customers and a poor reputation for companies. Today, elements of good and bad practice still exist both within and across companies in extend supply chains. It is important therefore for engineering design students to appreciate the difficulties in industrial practice and be able to work within the different approaches adopted.

3.2 The importance of clearly defining the design problem

Before a designer can start work on developing an appropriate design solution, there must be some understanding of what is to be achieved. Finding a solution is best achieved through initial understanding of the problem but defining it may prove to be a little trickier. It is often the case that defining the problem takes the form of describing a solution. The solution proposed may initially seem appropriate but unfortunately, as often the case, not for solving the identified need that has been initially identified. In engineering design the product design specification (PDS) may be initially prepared in some detail although some areas may be unclear and only vaguely in the early stages. In establishing the PDS it important to be as precise as possible as eventually information provided will form the criteria and basis by which achievement of the proposed design may be assessed [6]. Whilst the PDS is not rigid or "carved in stone" it is important to establish where necessary and as early as possible criteria rather than vague terms such as hot or cold, high or low, big or small. We cannot measure such terms and hence do not know if they have been achieved to our own or the customer's requirements. Reporting upon a design should eventually include assessing the proposed outcome against criteria established and defined in the PDS. This closes the loop having defined the initial need for a design it concludes with determining if the criteria identified has been satisfied. Therefore, teaching engineering design students to prepare and apply a PDS with self-confidence is critical to their capability at being good engineering designers in practice.

3.3 Learning from modifying existing designs

Much of the work carried out by designers in industry is not "clean sheet" design but concerned with existing designs needing modification or improvement to meet new specific requirements. This approach is beneficial to saving both cost and lead time for product development. In some cases it may be considered to be the norm for the majority of design work undertaken. However, this still requires considerable knowledge and understanding of the decision-making process that occurred in creating the original design. Changes to the design have to be carefully incorporated making sure any retained functionality is not compromised. This is generally not an easy task and for the inexperienced designer can lead to meeting requirements as in premature failure, for example, of the modified design due to incorrect assumptions being made and/or inadequate analysis. Arguably, this is a more realistic setting to be adopted for teaching design particularly if also done in conjunction with conceptual design and addressed in the context of the total design process. The student, like a novice designer, will benefit from gaining invaluable exposure to practical problem solving based on modifying existing designs. In this regard greater collaboration with industry is to be encouraged because engineering companies provide invaluable sources of existing design experience and could form the basis of extended team activities.

3.4 Designing as a team based activity

Design is undoubtedly recognised as benefitting from a team or group activity involving people from diverse backgrounds, knowledge and perceptions working collaboratively towards a single objective. Members of the design team must interact not only with other members but also with the prospective user/customer that may be inextricably entwined with social, organisational, legal and professional dynamics. Groups of individuals are not always easy to manage but groups of specialists who may have their own agendas are even more difficult. In teaching design there is an additional problem; students are generally not specialists, are not always focused on working as team members and are not renowned for delivering "on time". Can such diversity be managed in a smooth running and productive design team?

Teaching design in a full and meaningful way in a conventional educational environment is both demanding to organise as well as to manage. Individuals that show aptitude and ability for design are probably bettered trained by actually being allowed to learn on the job while working in and with design teams. As part of an educational course design teaching effectively requires entering a virtual world and best use has to be made of teaching staff, resource facilities, external sources and fellow students [7]. The introduction of group projects does attempt to mimic the professional team approach to design although a group of inexperienced individuals can be rather like the "blind leading the blind". As a result there is a strong need for student tutoring with regular review meetings providing an excellent way of monitoring individual and group progress and direction. However, the pressure exerted in educational establishments to reduce student contact hours together with increased group sizes makes this teaching task difficult to achieve.

3.5 Encouraging critical investigation in design problem solving

Engineering design may be considered as central to the teaching of engineering [8]. However, many colleges and universities have only taught design after a solid basis had been provided in related science and mathematics. This means that core subjects must have been studied to an appropriate level following that design is predominantly taught a final year subject. Design is the one subject that allows students to demonstrate their capabilities whilst indicating ability to self-manage, conduct research and successfully meet deadlines. More recent educational developments have meant that design is now taught in many first year courses. It is used as a means of enabling students to enjoy learning core subjects whilst becoming familiar with the process of design to manufacturing through an application of projects. A question that may be raised is one of whether the intellectual content of design is being underestimated? Designers try to predict outcomes even when those outcomes are the result of unanticipated actions. Using a Factor of Safety is employing a form of insurance into a design to cover as many eventualities as reasonably possible; manufacturing processes and materials variability, excessive usage and harsh environmental conditions and of course peoples behaviour are all considerations to be taken into account. Design requires constant questioning and for each question asked there might be multiple answers. Questions providing true or false responses or requiring specific values or other criteria are common in engineering. These require understanding and recall relating to knowledge based convergent thinking as when using scientific principles or mathematical reasoning. Decisions are often required, however, where no single or simple answer can be found or is reasonably available. Many possible outcomes may exist for any given situation which require selection of the most appropriate decisions based upon knowledge, experience and authoritative judgements. Such processes relate to concept or inquiry based thinking processes. Concept based thinking is the process of searching for an understanding by using the ultimate power of questioning, inquiry or research.

We all use the process of inquiry throughout our lives but do not necessarily develop it to a full potential. Convergent thinking is when the focus is upon coming up with a single well-established answer to a problem and operates in the knowledge domain emphasising recall and logic. It ultimately leads to a single answer which leaves no room for ambiguity being either right or wrong. Divergent thinking, however, operates more in the concept domain and generates creative ideas through the exploration of possible solutions. As such design thinking is a series of continuous transformations from the convergent domain to the divergent domain and *vice versa*, from thinking specific and narrow to thinking in general with many ideas being generated spontaneously [5]. Conventionally, engineering design teaching has concentrated on the convergent knowledge based subject areas where outcomes may be accurately predicted. This has been the focus for conventional examinations such as in the subject areas of Engineering Sciences and Mathematics. The teaching of divergent enquiry tends to be considered only as a side issue or even a luxury. We are not taught or encouraged to think divergently and hence we are not taught to develop powers of honestly criticising outcomes to obtain the most appropriate for the given situation. Design does require input from low-level understanding demanding deep reasoning and convergent questioning. There is also a need for a more open and divergent approach generating conceptual aspects upon which the convergent components may eventually hang. The inclusion of results for both convergent and divergent activities should be described in any design report written by students. To achieve this in teaching engineering design it is important to achieve an appropriate balance in the teaching of the knowledge centred convergent domain and the more open-ended divergent domain. With more discerning customers demanding ever greater range and variety from cheaper products, the importance of both convergent and divergent thinking within the design process becomes apparent.

4 CONCLUDING REMARKS AND WAY FORWARD

The paper has outlined some of the main issues surrounding the teaching of our future engineering design students. These have intentionally been placed in the context of industrial practice. The outcomes presented are the result of considerable course validation experience rather than on an academic research investigation. As a consequence key areas for improvement and best practice have been recognised. Design educators are encouraged to adopt a more holistic approach to skills development with an emphasis on practical skills when teaching students. This is helped by project work with greater collaboration with industry. The teaching methodology should reflect the analytical rigour of a structured design process. The need for developing deeper knowledge and understanding delivered through real problem based scenarios is essential. There is considerable benefit in working and learning more from peers through team based activities but this must be carefully managed to ensure a coherent participation of individual students. Finally, developing students' ability in critical inquiry is essential facilitated by an appropriate use of theoretical and practical means to justify outcomes.

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