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# CROSS-DISCIPLINARITY WITHIN ENGINEERING

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**ABSTRACT**
From the outside, engineering is often thought of as a single field, but on the inside this is far from the case. In the UK, there are currently 35 professional bodies registered with the Engineering Council. These have grown up over the last two centuries, often co-operating but each defensive of what they see as their field of expertise. Even today those fields can be jealously guarded and cross-discipline demarcation can occasionally get in the way of coherent design work. Engineers from one field may not understand the requirements of others. Even the language used in one area can be confusing in others.
Interfaces between different technologies can be overly constraining. If an opportunity to use a component for more than one function is proposed, the negotiations can be prolonged. When the engineering team has to consider non-technological factors, with product designers and others, things can get even more complex. This paper examines those historic divisions and asks if they are still valid and how barriers to collaboration, within and beyond engineering, can be broken down with a more flexible approach. Engineers from different backgrounds need to work together and understand each other's priorities. This has implications for academia and the whole design profession.

*Keywords: Cross-disciplinarity, professional bodies, engineering course development.*

## 1 UK HISTORY

In 1771, the Society of Civil Engineers was formed by John Smeaton, bringing together some earlier groups. Here the word "civil" was used to distinguish them from military engineers. In 1818, the society (by then known as the Smeatonian Society after his death) became the Institution of Civil Engineers, ICE. It gained a Royal Charter in 1828 becoming the first engineering professional body in the world. At this time, most engineers were working on the expanding canal network, and the institution claimed to represent all civilian engineering work (as still stated in its Royal Charter).
Then along came the railways. Being a rival technology to the canals, there was some resistance to allowing railway engineers into the ICE. In 1847, these tensions led to the formation of the Institution of Mechanical Engineers, IMechE, "to give an impulse to invention likely to be useful to the world." The foremost railway engineer in the country, George Stevenson, was invited to be its first president, but it did not confine its interests to the railways.
The Royal Aeronautical Society, RAeS, was established in 1866 "to further the art, science and engineering of aeronautics". At that time, they were concerned with ballooning, both hot air and gas filled. They generally regarded proposals for "heavier-than-air" flying machines as not worthy of consideration. When they did begin to consider aircraft, they met with considerable opposition.

*"I have not the smallest molecule of faith in aerial navigation other than ballooning.... I would not care to be a member of the Aeronautical Society."*
*Lord Kelvin, physicist, President of the Royal Society, 1896.*

The Institution of Electrical Engineers (now part of the Institution of Engineering and Technology, IET) was founded in 1871 as The Society of Telegraph Engineers. More organisations were formed with interests in shipbuilding, mining, metal working, chemical processing and more. Common interests in manufacturing were represented by the Institution of Production Engineers, now also absorbed into the IET. Similarly, broad interests in design led to the formation of the Institution of Engineering Designers, IED, in 1945. Thus some bodies worked in single industries, some with particular areas of expertise and some covered specific tasks, and this remains so today. Their distinct natures make it difficult to evolve a more rational structure without starting again.

Many of these bodies operate outside the UK with significant numbers of overseas members. Engineering professional bodies in other countries have tended to have similar underlying divisions to those in the UK, with the same demarcation problems, even though their overall structure and legal status may be very different. Internationally, there are systems in place for mutual professional recognition. In Europe, 32 countries subscribe to FEANI(1), granting the title "Eur Ing" to those qualified.

The Council of Engineering Institutions was established in 1965 as a joint UK forum and was superseded by the Engineering Council, EC, in 1981, with statuary powers, following the Finniston Report (2) on the profession. At that time, they watched over 54 individual professional bodies. A succession of mergers has since reduced this to 35 (at the time of writing). These range in size from 160 000 (IET) to several under 100. The EC is the national representative body for the whole profession and sets broad standards for qualification and recognition published originally as "Standards and Routes to Registration" (SARTOR), which has now evolved into "UK-Spec" (3). Each institution sets its own requirements for membership within the framework of the EC standards and monitors conformance. (For more historic detail see (4)). The three editions of SARTOR focussed on the necessary content of accredited courses. UK-Spec details the requirements for registration, of the various types of engineer, no matter how the applicants have acquired them.

The introduction of the EC requirements changed the pattern of design courses in UK academia. The spectrum of courses, from heavily theoretical "engineering science" to the more "aesthetic" end of product design, was split between those that wished to meet the requirements and those who saw them as too constraining. However, the requirements contained a Trojan horse. The only mandatory requirement in SARTOR was that all courses must contain design, quoting requirements from the UK Design Council's "Engineering Design Education" report (Moulton Report) (5), which said, "All engineering should be taught in the context of design and design should be a thread running through the course." This caused strain in the scientifically orientated courses, where design did not easily fit. Those courses with a more practical approach were soon introducing design based project work backed up by a growing amount of teaching materials. Some of these were produced by "Sharing Experience in Engineering Design" (SEED), an organization promoting design in engineering courses later becoming part of "The Design Society", one of the sponsors of this conference.

## 2 CURRENTLY

Today, the older historic divisions are most obvious in academia. Courses tend to be concentrated within the fields defined by the early professional divisions. Universities often have separate buildings for mechanical, civil, electrical and more, with staff who rarely meet, even though they may be teaching or researching closely related topics. In industry, most projects are now labelled as "multi-disciplinary" because they require expertise from several of the recognized academic disciplines. The implication is that the field boundaries have changed but the representative bodies and academic structures have not kept up. It seems irrational to fiercely protect historic boundaries which are no longer particularly relevant. Narrow specialization is the norm for research active academics, but the students they teach will have to cope with a broader based, multi-discipline environment once they graduate. Product Design academics frequently research the broader aspects of design evolution, but their engineering colleagues rarely seem to wonder how the engineering activity itself can be improved.

In the UK, there is no legal requirement for professional registration, except in a few safety critical areas. Thus perhaps only 25 – 35% of those who qualify are registered. In industry, design teams often contain engineers with different professional affiliations, or none, without the others being aware of it. Their past experience and expertise is seen as more relevant both for recruitment and practice. However, a growing number of companies are now taking professional registration into account for recruitment with a bar to promotion for those not registered. Professional bodies often see each other as rivals when recruiting members, even though individuals may be members of several bodies, particularly if they feel that no one body provides all they are looking for.

As we have seen, the current set of engineering bodies grew up in a haphazard way, as a need was felt, and not with any concept of an overall structure. Many of the original reasons for their separate existence have changed of even disappeared over the years. With canal building now a rare activity, the ICE now covers all aspects of the construction industry; the IMechE applies mechanical expertise in a number of industries; and the IED has interests in design activities across the whole engineering field and beyond into product design and more.

## 3 AREAS OF CONFUSION AND CO-OPERATION

Few mechanical engineers know the details of reinforced concrete design, timber or masonry structures, or the complications of foundations in soft soils. Few civil engineers could tackle the analysis of a carbon fibre wing structure or the impact loading on a railway vehicle. Even so, both might consider themselves as having structural design expertise. Where they interface, such as in the foundation for a diesel generator set, both sides tend to be overly conservative, often resulting in unnecessarily heavy and expensive designs. Multi-disciplinary design inevitably produces challenges at the interfaces between disciplines. These may be physical, as in the foundation above, or a clash of concepts, where one side does not understand the reasoning of the other.

Projects with a significant input from a number of areas of expertise can fail if each group holds rigidly to the importance of their requirements. Conversely, a very successful design can result from a flexible approach, where each group minimises and modifies their demands to accommodate the priorities of others. The result can often be a product which the design team are proud to have worked on.

I learned about structural analysis and design as part of a first degree in civil engineering. I transferred that expertise into the space industry, working on several European and American projects, then into high-speed railways in the UK. In all three industries, the underlying structural expertise required was virtually identical. The materials and manufacturing methods were different, as were the scales, tolerances and quality control systems, but the structural understanding and analysis were fundamentally the same. I had no difficulty adapting, so expanding my expertise. Even so, other engineers sometimes expressed surprise that I had changed industries, not believing how transferable an expertise can be.

In the UK, there is the Institution of Structural Engineers, but they are only concerned with the construction industry. Courses in mechanical, aerospace, chemical, naval architecture and more also teach structural analysis and design in some depth (although they often call it "Mechanics of Solids"). All UK engineering courses must include some basic structural understanding and often use the same text books. Most professional bodies claim to have an interest in structure, but they rarely interact to consolidate that common ground into a broad understanding of the concept of structure, the thing which gives all solid objects solidity no matter who designs them.

## 4 OTHER DESIGNERS

In my experience, when working with product designers, or others with different expertise, engineers tend to accept them in the same way as other types of engineer, deferring to their knowledge and responsibility for the decisions they take. This usually works, but may run into problems when a non-engineer cannot give a practical justification for a proposal. Engineers can usually back up their viewpoint with analysis or experience. This is not always the case in other fields. (Architects may prefer glass boxes, even when exposure to the sun causes overheating, as pointed out by the heating and ventilation engineers.) The problem is again one of communication and understanding by both sides. Each has to appreciate the other's viewpoint, even if this means carefully explaining things using language and concepts the other is more likely to understand. Part of the misunderstanding between the two is often a narrow interpretation of the concept of design by individuals on both sides.

I have no doubt that similar divisions disrupt relations between other areas of design. However, the breadth of modern engineering tends to produce specialization and the rise of more potential areas of misunderstanding exacerbating the problem.

Design does not happen in isolation. Whatever the market, there are always users and purchasers, manufacturers, distributors and more directly involved in the supply chain. In addition, other factors to include may be storage and transport, installation and commissioning, and maintenance and disposal. All this happens within organizations with investment, management and future planning considerations (5). The design activity itself has become an exemplar of sensible planning with "Design Thinking" now being promoted as a management philosophy. Thus designers may be appreciated as able to contribute to the broader thinking within the organization. Sadly, it's more likely that managers will be given a quick course in Design Thinking and will start telling designers how to do their job having never designed anything themselves. Worse, they may think that they can do the designing and don't need experienced design staff.

## 5 EDUCATIONAL IMPLICATIONS

It would be all too easy to suggest that the professional and academic divisions of the engineering field should be re-considered, but this would not be a simple task. Across engineering, the technologies, materials and manufacturing methods used have radically changed in recent decades. Industrial boundaries are becoming blurred. For example, many major assemblies used in the construction industry are now made in factories to tolerances more often used in mechanical engineering. Thus civil engineers have to adapt their design thinking and require higher accuracy on construction sites. (Luckily, new laser based methods of surveying can meet the requirement.) Professional bodies are holding more joint events highlighting areas of mutual interest and more amalgamation proposals are under discussion. The growing influence of computing methods shows that software developed for one purpose may be useful in very different areas. (I once adapted a thermal radiation program to determine the areas of a spacecraft exposed to micrometeoroid impact.)

Engineering academics tend to focus on their specialist research interests and are most comfortable teaching its underlying basic analysis. This means that students rarely get an overall view of the breadth of engineering and the interaction between subject topics. Even design projects are often narrowly focussed on problems familiar to the academics supervising them. In the worst examples, projects become a contribution to the research programme itself and are assessed on that basis. It is important that design projects are framed as open ended customer requirements, with students encouraged to take an imaginative approach. The final project should be a demonstration of the student's ability to act in a professional way in tackling a realistic problem, even when the focus is not on the design of an artefact. I used to tell my students that within two weeks I expected them to know more about the design challenge than I did, but I would continue to act as a conduit to detailed technical expertise and gave constructive critiques. Student design work can be a useful learning experience for the supervisor as well as the students.

Management is often taught on engineering courses by service teaching from a "business" school. This has led to topics such as bookkeeping and economics being taught rather than more applicable ones such as project management or patent application (although most business schools don't really have much expertise in these areas). With the promotion of design thinking in management, this should change, with engineering or product design departments passing on expertise to management students.

From the earliest introduction of engineering courses in UK universities late in the nineteenth century, there have been cross-disciplinary activities. Cambridge University, for example, still has just one engineering department, with students not choosing specialisms until later years, although many topics are taught across the courses. Other universities have interaction between departments, but many have none. Parts of the academic world have been introducing team design projects using students from different departments, sometimes including Product Design. This broader understanding should be encouraged and design is a useful activity for enlightenment. It also gives students a more realistic view of the challenges an engineering career can present.

Recently a new type of engineering course has been introduced in a number of countries (including at the university hosting this conference). The CDIO (Conceive, Design, Implement, Operate) structure (7) requires a strong project approach to learning about engineering, which is closer to that of many product design courses. A series of projects provide an incentive to learn the necessary information, supplied via a tailored lecture programme, and gain the understanding needed to complete them. A carefully compiled series of projects covers the same syllabus as a more traditional course, but the levels of understanding and enthusiasm produced tend to be much higher. Staff need to learn to work together acquiring a broader more imaginatively flexible approach to provide the level of mentoring required.

## 6 CONCLUSIONS

Engineering practice is changing. In industry, the need for flexibility and the need to adopt new techniques and adapt to changing markets always has been necessary to stay in business. Engineering teaching is changing. Some of the new technologies being introduced in industry have arisen from engineering research in universities, but that knowledge and understanding is slow to percolate through to the undergraduate teaching. Credit, and promotion, is more often earned through the ability to attract research funding and publish papers than by improving the course teaching or passing on their finding to industry. Textbooks inevitably lag behind the pace of change, so teaching based on them can become outdated beyond basic factors. Ironically, many product design courses have given students routine access to manufacturing technologies such as plastic moulding equipment and 3-D printers years before their engineering colleagues. Product design methods centre round a series of models ranging from rough sketches to production prototypes, each stage refining both the physical realization and the underlying concept of the product (8). It is not surprising that these courses incorporate new convenient forms of model making ahead of their engineering counterparts.

The old dominance of "engineering science" is fading to be replaced by a more pragmatic approach with CDIO and other approaches showing what can be done. Engineering courses at universities originally adopted a scientific approach in order to be more acceptable to the academic community. With this mind set, the production of papers was seen as the key activity. Some 150 years later, we are seeing engineering establishing its own separate academic identity and closer links to the profession it serves. With the growing influence of industrial sponsorship, the applicability of engineering research is becoming paramount. Often, fewer papers can be published since much of this research involves proprietary information, but the facilities and techniques which result are usually available for a broad range of research sustaining a vigorous long term programme.

Processes need to be in place to encourage engineering academics to incorporate the results of their research into undergraduate teaching as early as possible, particularly where those results have a potential for broader application. Such activity should be recognized for promotion, rather than simply counting the number of published papers.

I used to tell my students

*"Science compares theory with reality, in order to improve the theory.*
*Engineering compares theory with reality, in order to improve reality."*

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