

MEMS – Making Engineering with Management a Success

Kevin Kelly

School of Engineering, Trinity College Dublin.

ABSTRACT

This paper reflects on the development of the Engineering with Management degree programme - formerly known as Manufacturing Engineering with Management Science - developed and brought to fruition under John Monaghan's leadership of the department, and benefiting from his guidance and support in those crucial early years (and beyond). The context and need for the programme is developed, along with a brief history of the course and its development through the years, concluding with a snapshot view of the programme at present. The evolving higher education context, within and beyond Trinity is considered along with lessons to be learnt from our peers and from the literature. The paper concludes by looking at the challenges and opportunities ahead, and how the programme might respond.

1. SOME HISTORY AND CONTEXT

Manufacturing in (the Republic of) Ireland has had a markedly different history to that of our neighbours in northern Ireland, where the region, and Belfast in particular, was a powerhouse of the Industrial revolution, with world names in the textiles, shipbuilding & aircraft sectors to name but a few. The rest of Ireland by contrast was a predominantly agrarian economy until (at least!) the 1940's, where under the successive governments, there was a broadening of our industrial policy, leading to the formation of the IDA in 1949. The activities of the IDA in bringing in foreign direct investment to Ireland, augmented strong performance and growth in our domestic food and beverage production. Ireland's entry to the European Economic Community (EEC) in 1973 was a further enabler, although it was far from plain sailing as successive oil crises in 1973 and 1979 had pronounced and prolonged negative effect on the world economy, including Ireland. Manufacturing in Ireland was not immune to these events, prompting the government of the time to commission the National

Economic and Social Council to produce a report entitled “Analysis of Job Losses in Irish Manufacturing Industry” [1]. It is interesting, albeit with the benefit of hindsight, to examine the makeup of the NESC (10 appointees of the Government, 10 of the Employers bodies, 10 of the trade unions and 10 of the agricultural organisations, supplemented by 1 representative from each of the 6 ‘related’ government departments, plus a chairman). It is a wonder that any work beyond handing out the tea and coffee was ever achieved! The report itself was authored by a trio comprising two economists and a civil servant, and that bias is reflected in the nature of the analysis, although there is an interesting chapter on how the authors believe the microprocessor will affect Irish industry (summary: they were pessimistic!). The general conclusions of the report are a little vague - bringing to mind President Truman’s apocryphal request for a one-armed economist! One is prompted to wonder what kind of analysis might have been performed, and conclusions reached, if a newly ‘doctored’ manufacturing academic, with diplomas in statistics, management and computer science has been asked to contribute....

As has been elucidated elsewhere in this book, John was employed by TCD in 1980 as part of cadre of new staff to resource the expansion of the School of Engineering, and the inception of discipline specific education - one part of which was the establishment of a specialisation in mechanical and manufacturing engineering. The first graduate student activity (excluding that of John himself!) began in 1981, and the Irish Manufacturing Conference was initiated in 1984, highlighting the maturing of manufacturing as an academic discipline in the Irish context.

The late 80’s saw an increase in foreign direct investment in Ireland with a consequent increase in manufacturing output - notably in the pharmaceutical and ICT sectors, followed later by substantial growth in the medical device sector. Indeed figures presented in ‘The Future of Manufacturing in Ireland’ interim report from the Irish Academy of Engineering [2] note that employment, in manufacturing, grew on average by 2% per annum over the period from 1958 to 2001, and that productivity per employee grew by an average of 6% per annum over the same period. In that context there was a need and an opportunity to provide a new manufacturing engineering programme in the Irish University sector. The late Prof. John Fitzpatrick, then head of department, embraced the challenge and the newly appointed lecturer in manufacturing systems, Kevin O’Kelly was tasked with exploring the possibilities. Kevin worked diligently on these proposals, noting as part of his research that a growing trend in top international universities was ‘integrated’ curricula with elements of business, management and operations research taught along with the technological fundamentals. In parallel, the (American) Accreditation Board for Engineering and Technology (ABET), following a decade of

development, adopted its Engineering Criteria 2000 approach - a revolutionary (for the time) approach that focused on (learning) outcomes rather than the traditional (teaching) input, and placed very strong emphasis on transversal skills such as teamwork, ability to engage in lifelong learning etc. [3]. 'Back home', informal surveys of graduates and business schools at the time revealed some interesting additional evidence in support of a new programme of this type:

- approximately 70% of engineering graduates were within principally managerial (rather than technical) roles within 5 years of graduate,
- nearly 80% of 'B-stream' graduates were gaining employment in manufacturing related industry, and
- some 30% of entrants into Irish MBA programmes had a primary qualification in engineering.

The case seemed clear-cut, but as is often the case in academic environments, the progress was not always linear! By this time, John Monaghan had succeeded John Fitzpatrick as head of department, and it required all of his considerable drive and diplomatic skills to negotiate some of the early challenges. Eventually, sense was to prevail and internal college approval was complete by December 1999.

2. THE START OF SOMETHING NEW

September 2000 saw new ground being broken, with the author being hired and the first intake of students. 11 students began their studies in the new programme, TR038 - Manufacturing Engineering with Management Science, or MEMS as it was commonly known. A delay in acquiring all the necessary approvals meant that it was not offered in the February round of CAO offers that year, resulting in a smaller number of applicants and a first year points 'threshold' of 330 points - by comparison the General Engineering degree had a requirement of 420 points. The course structure, in first year, was strongly based on that of the General Engineering degree, augmented by modules from the MSISS programme and a specialist module in Manufacturing, delivered by John and the author.

This expansion of activity had received approval from the HEA, and most tellingly and importantly, this was not just in principle - hard cash followed. The concurrent expansion of research activity in the Trinity Centre for Bio-Engineering facilitated the construction of a new extension to the historic Parsons building to provide teaching and research space for these new activities. John's steadying hand was key during this time as internal and external threats to the funding continued. However he was to have his reward in 2004 when the building works were complete (we all like bare concrete finishes, right?); a fitting way to conclude his second term as head of department.

As the programme began to develop, the ‘two Kevins’ (or Father and Son, as John liked to refer to us...) were often to be spotted in conclave, planning the evolution of the curriculum and how the latest pedagogy and educational thinking could be incorporated. Running a new degree programme is a challenging exercise with much stress, many decisions and a high workload, but the flipside is that it can highly invigorating to have the opportunity to implement change in an agile manner - in engineering terms, to design and manufacture a program, or to borrow a term from a philosophy that was influential in shaping our thinking - to Conceive, Design, Implement and Operate a program. Through these years a distinct philosophy began to emerge - small group teaching (where possible), a strong emphasis on design, an integrated pedagogy of technology and business and a determination to avail as much as possible of opportunities to replicate international best practice in engineering learning - in areas like project based learning, flipped classrooms, CDIO. John and his confrère Garry Lyons (the Waldorf to John’s Statler!) were enthusiastic supporters of such initiatives, with John providing much useful guidance and advice in the development of the manufacturing stream - the new programme perhaps finally giving a redress to his frustration at only having 1 ½ courses of Manufacturing Technology available to him for all those years!

Further new staff followed - Paul Davis in 2003, to be replaced by Garret O’Donnell in 2005 and Biqiong Chen in 2008 to be replaced by Shaun McFadden in 2012 (himself replaced by Daniel Trimble in 2015). More recently, on John’s official retirement (although he has continued to provide teaching for us in this busy and understaffed area), Rocco Lupoi was appointed in 2012, and Conor McGinn (as a temporary replacement for Kevin O’Kelly) in 2014. Teaching development continued and key milestones were reached, as we graduated our first class in 2004 and underwent accreditation for the first time in 2006. John was again to prove invaluable here - his experience within the IEI (as was at the time) as an accreditor and also as an external examiner, helped to us to gain full 5 year accreditation - a notable success for a new programme. In particular, there were many compliments for the innovative teaching and assessment methodologies - many of which have since been rolled out across the school of engineering.

Other notable milestones as the course grew were the first Engineering with Management Foundation Scholar - Rory Stoney (2007), the first E&M post-graduate (Peadar Golden with an MSc in 2010), the first PhD graduate (Paul Harris, 2011) and the first Unitech exchange student (Cian McGrath in 2011).

3. A SNAPSHOT IN TIME – E&M IN 2015

Almost 20 years on from the first discussions on a new programme, 15 years from our first intake and just over ten years from our first graduating class, it is perhaps timely to look at how the programme has developed since those early years.

In common with the BAI programme, the ‘default’ offering is now a 5 year integrated Masters programme leading to an MAI degree - for both entry routes (older doubts about ‘purity’ etc., seem to have been assuaged...) in accordance with the Bologna process and the new standards for accreditation of Chartered Engineer status. The curricula of both engineering programmes have evolved in line with the principles of CDIO, and indeed the new accreditation process brought in by Engineers Ireland in the early 2000’s (closely modelled on the ABET criteria discussed above) - introducing substantial project work in the early years of the degree. Both programmes now provide 6-month internships as an option for students in the first year of the masters cycle. Strong international links have been developed through the CLUSTER network and students in the school of engineering are increasingly availing of the opportunity to broaden their education through a year spent studying in another country. As one might expect, the general experience for both the students concerned and for their classmates on their return is very positive - they typically bring heightened maturity, knowledge and focus to their studies on their return - being demanding both of themselves and of those around them - including the academic staff! We have seen increased internationalisation within our programmes as well, with the recent joint initiative with Thapar University in India and the popularity of the E&M programme (in particular) with Brazilian students funded under the Science Without Borders initiative.

Particular developments of note are the high level of use of flipped learning (e.g. 1MEMS4 - Introduction to computing) and reflective learning (e.g. 2MEMS10 - Manufacturing Engineering Design project) as well as high levels of ‘horizontal integration’ between modules at various levels - a good example being the ‘Guitar project’ exercise in second year which integrates subjects including Design Theory, Manufacturing Technology, Materials, Finance and Computer Aided Engineering - as well as delivering strongly under ‘transversal skills’ such as teamwork, communication, life-long learning etc. These initiatives draw strongly upon the best practice reported in the literature, e.g. Campos et al [4]. A notable recent addition has been the increased focus on design innovation, with the new ‘4E5 - Innovation in Product Development’ module in the masters cycle having teams of students collaborating with global university and industrial partners to develop innovative solutions to open-ended and challenging problems posed by the industrial partners. The pedagogy of user-centred design is

well accepted in the academic community, see for example Dym et al [5] and is of increasing interest to industry as many market leaders such as Apple, SAP, Google and Dyson are strong proponents of such an approach.

The maturing of the course and the introduction of initiatives such as the above has helped to increase the popularity of the programme, as evidenced by the CAO points required for entry, shown below (BAI also shown for comparison).

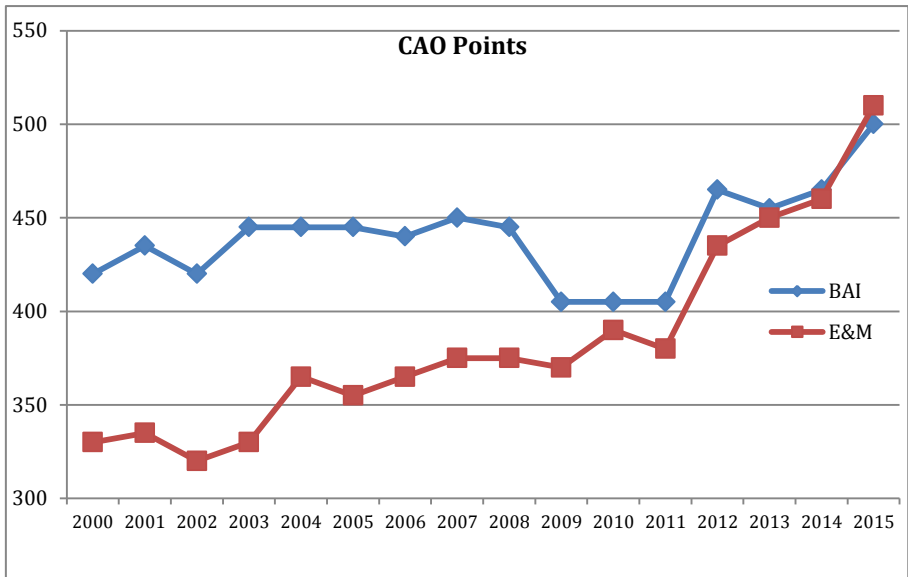


Figure 1. Student demand for places in engineering with management through the years

4. LOOKING TO THE FUTURE – EXTERNAL FORCES

Manufacturing comprised 24% of Irish GDP in 2009, employing 11% of the workforce, and even allowing for transfer pricing practice can be seen to be a key component of the Irish economy [2]. The UK remains a key trading partner, particularly for the 53% of manufacturing companies that are Irish owned. Manufacturing has been identified as a key element of Irish economic policy, and indeed worldwide. For example, the ‘Future of Manufacturing’ report from the World Economic Forum in 2012 [6] notes that there are approximately 10 million jobs worldwide in manufacturing which were unfilled, due to skills gaps, and predicts that talent will be a key future differentiator. Other key differentiators identified are the strategic use of public policy and the ability to innovate. More locally, the Forfas report ‘Making it in Ireland: Manufacturing 2020’ [7] and the Irish Academy of Engineering report [2] draw similar conclusions and note some of the

challenges ahead - e.g. total output (i.e. both productivity growth and increased employment) from the Irish manufacturing sector will need to increase by an average of 10% per annum over the next 5 years to meet overall economic targets. We can clearly see that we have a major societal challenge in producing the engineering talent to meet these needs, but what is inarguable is that there is, and will continue to be for the foreseeable future, a strong need for skilled graduates in manufacturing.

Let us turn to the supply side, and issues affecting the output of graduates. Many of these issues are dealt with in detail elsewhere in this volume, so this paper gives only a cursory overview. Higher education is becoming increasingly internationalised - for example, the 2012 OECD Education at a Glance report [8] indicates that the number of students studying abroad more than doubled between 2000 and 2010, with no sign of a slowdown since then. Costs are rising in many countries - figures available from the Bureau of Labor Statistics show that tuition costs in the US have risen approximately 650% in the last 30 years, compared to rises of approximately 300% in medical care and 100% in general consumer prices [9]. This threatens to create a more stratified 'market' for higher education, with premium institutions leveraging their 'brand' to charge higher fees. New developments in online learning threaten (perhaps with a less convincing voice at this point...) to disrupt the area of higher education, with companies such as coursera, edX, Udacity and NovaEd entering the marketplace. Closer to home we have seen a growth in higher education numbers, particularly in the STEM area, with the recent discussion paper from the Expert Group on Future Funding for Higher Education [10] predicting that even with no growth in the current participation rate of 56%, the numbers enrolled in higher education will increase by $\frac{1}{3}$ in the next 10-15 years. In parallel government funding has decreased by 22% per student. Even more locally, the 2013 Engineering School Quality Review [11], and discussions around the new E3 [12] institute forecast growth of student numbers of the order of 40%.

5. CHALLENGES AND OPPORTUNITIES

The challenges are many, and have largely been enumerated above and elsewhere in this volume. They are summarized below:

- A trend of decreasing government funding, per capita, and an increasing privatization of higher education, coupled with an apparent lack of political will to allow a return of higher education fees.
- A large increase in demand for STEM courses, and Engineering in particular

- Pressures from industry, government and education to provide a wider range of skills in our graduates, at a time where the half-life of knowledge is decreasing rapidly [13]
- Space constraints and issues – many of the historical buildings are a poor fit for a modern engineering school, and in an absolute sense the physical space available is very limited – particularly in the area of mechanical & manufacturing engineering with approximately 200% more students than 5 years ago.

It should be acknowledged too that there more obviously positive changes in the pipeline also, which present opportunities, viz:

- A new engineering building to house E3 (Engineering, Energy and the Environment), to provide 22,000 sqm of usable space (shared with Natural Sciences)
- A strengthening of university-industry relationships through developments like the Engineering School Advisory Board, the Engineering internships
- Developments in technology-enhanced learning and online learning offer opportunities to extend and augment our capacity to interact with students
- Increasing links with top universities around the world help to expose us and our students to the latest developments in both technology and pedagogy.
- Increasing awareness within and outside of TCD of the importance and scholarly potential for engineering education research – e.g. the STEM-ERC group in TCD and the CREATE group in DIT, a strongly supportive speech from IRC director, Eucharua Meehan, at the STEM Education Research workshop in DIT in May 2014.

6. LESSONS FROM THE BEST

Taking onboard the challenges (and opportunities) identified in the previous sections, it is perhaps useful to look to the engineering education literature, to see what might be applicable in the context of manufacturing education in TCD. In what is an enormous canon of research, the following is inevitably a somewhat selective and personal summary.

An early (but often ignored) question that arises is with regard to our student intake – how do we know that we are admitting (and retaining) the ‘best’ students, and furthermore, what do we mean by ‘best’? These questions were addressed in the FP7 project ‘ATTRACT’ [14] – which concluded that ‘best’ in this case could be defined as most motivated to pursue a career in this area, predicated on informed choice, and that any ‘rationing’ necessary (to balance supply of places with demand) was best

done on correlates/predictors of student progression. Among the findings were that:

- The perception of the engineering profession amongst potential students is generally positive in terms of the contribution to society and self-professed understanding of the profession (a point examined later), but with something of a disconnect in that a relatively small percentage of students perceive it as an option for them personally. Amongst the typical reasons stated were that it was ‘hard’ (something also shared with medicine, albeit with maybe more societal status for medical studies/practice as an explanatory factor). This was particularly prevalent for female students.
- Actions to promote engineering as a study choice, should endeavor to make use of role models (particularly with regard to female students), and should make use of active learning styles to maximize impact of such activities over time [15].
- Engineering programs tend to have high attrition rates compared to many other disciplines. Conclusions from the literature [14] are not uniform as to why, but common reasons cited include the heavy workload, poor understanding of what engineering as a profession and course of study involves (in contrast to the self-professed good understanding of prospective students), difficulties with social integration, mathematical competence and pedagogic structure of the programs.
- Mathematical attainment at secondary level is a key predictor (of student progression), along with performance in subjects such as physics, chemistry and construction studies [16]. The latter is somewhat interesting and resonates with the findings of Sorby [17]. Gender differences in attainment in these subjects at the pre-university level, even when normalizing by average grades, was noted [17], in keeping with the consensus in the literature [18].

Now that we have addressed the questions of who our students should be, and how we should attract them, we might next turn to the pedagogy we employ. There are (inter-related) questions over what we teach and how we teach. The technical content of what we teach is perhaps in some ways easier to identify, but we should cognisant of over-specialisation or of simply providing information without context. Much attention has been given in recent years to the metaphor of the ‘t-shaped’ education [19], where ‘horizontal’ integrative skills and experience are married with ‘vertical’ deep skills in a chosen discipline. This brings us to curriculum design. The CDIO philosophy [20] is one that is gaining increasing traction in engineering schools, including that of TCD. The philosophy begins with a proposition that the transition of the engineering education profession from

being one of practice-based skills acquisition through mentorship to being a research-based ‘academic’ discipline saw a ‘golden age’ (approximately the 1960’s) as nexus of (older) distinguished practitioners co-existed in academic environments with a cadre of (younger) engineering scientists. Furthermore that this golden age passed/faded as the practitioners were replaced with (younger) engineering scientists, and that the balance of the education given to students suffered. The CDIO philosophy espouses a learning approach based on a Conceive-Design-Implement-Operate cycle – essentially students learn through identifying and implementing solutions to problems. It has, therefore much in common with the inductive learning methods such as problem based learning [21]. Implementation of CDIO compliant programmes is not without its challenges, as identified in [20] as it requires move from more ‘traditional’ passive learning styles towards more active learning styles. Doubters may be reassured however that such learning styles do actually bring benefits, as demonstrated in the comprehensive study by Prince [22]. An interesting development in these design-based educational philosophies is the product-based-learning paradigm, perhaps best exemplified in the user-centred design program ME310 taught at Stanford University [23].

7. SUMMARY

This paper has charted the development of a new manufacturing program from concept to reality – paralleling the typical sequence of a ‘real’ manufacturing enterprise. The key influence of John Monaghan in its design and development, particularly in the early years, has been elucidated. The evolving context, both educational and economic has been noted. Challenges and opportunities have been detailed, and the best practice in engineering education as documented in the literature has been noted. From this knowledge base, the author suggests that key features of a world-class manufacturing education program in the future will include:

- Attraction of the best and most motivated students into the programme
- Active learning, particularly with project, product and problem based styles
- Core competence in the latest manufacturing technologies at both a theoretical and practical level
- Strong ‘t-shape’ skills in communication, teamwork, self-learning
- Pedagogical links with top universities as part of the taught programme
- Meaningful, structured interaction with industry, including internships, joint projects and summer employment
- Detailed and immersive exposure to international quality research

- Clear pathways with defined intersections allowing students to progress to research, industry or entrepreneurship/innovation.

8. REFERENCES

- [1] National Economic and Social Council (1983), Analysis of Job Losses in Irish Manufacturing Industry, Available at http://files.nesc.ie/nesc_reports/en/NESC_67_1983.pdf, last accessed at 13th August 2015
- [2] Irish Academy of Engineering (2013), The Future of Manufacturing in Ireland - Interim Report, Ref.: 02/01A/10.13, Available at <http://www.iae.ie/publications/publication/the-future-of-manufacturing-in-ireland-interim-rep/>, last accessed at 13th August 2015
- [3] ABET (2015), History – ABET, Available at <http://www.abet.org/about-abet/history/>, Last accessed at 13th August 2015
- [4] Campos, L, et al. Project Approaches to Learning in Engineering Education: The Practice of Teamwork. 2012, *Sense Publishers*, Rotterdam.
- [5] Dym et al, Engineering design thinking, teaching and learning, (2005) *Journal of Engineering Education*, 94 (1), pp. 103-119
- [6] World Economic Forum (2012), The Future of Manufacturing, , available at <http://www.weforum.org/reports/future-manufacturing>, last accessed at 13th August 2015
- [7] Forfas (2013), Making it in Ireland: Manufacturing 2020, Forfas report, available at <http://www.djei.ie/en/Publications/Making-it-in-Ireland-Manufacturing-2020.html>, last accessed at 13th August 2015
- [8] OECD (2012), "Indicator C4 Who studies abroad and where?", in OECD, Education at a Glance 2012: OECD Indicators, OECD Publishing, Paris.
- [9] Raw figures available from Bureau of Labor Statistics, <http://www.bls.gov/data/>
- [10] Expert Group on Future Funding for Higher Education (2015), Interim Report, available at <https://www.education.ie/en/The-Education-System/Higher-Education/Higher-Education-Expert-Group-on-Future-Funding-for-Higher-Education-Discussion-Paper-for-Stakeholder-Consultation-.pdf>, last accessed at 13th August 2015
- [11] Engineering School Quality Review Panel (2013), Quality Review Report, available at https://www.tcd.ie/Engineering/assets/pdf/QualityReview2013_FinalReport.pdf, last accessed at 12th August 2013

- [12] School of Engineering, E3 Strategy Report, available at <https://www.tcd.ie/E3/assets/pdf/E3-strategy.pdf>, last accessed at 12th August 2015
- [13] Arbesman, A., 'Be Forewarned: Your Knowledge is Decaying', *Harvard Business Review*, November 2012.
- [14] Hanson et al, ATTRACT Project Final Report, available at www.attractproject.org, last accessed at 12th August 2015.
- [15] Kelly et al., 'Engagement With Second Level - Does It Work?', *29th International Manufacturing Conference*, Belfast, Ireland, 29-30 August 2012
- [16] Kelly et al., 'Prediction of Student Performance In Engineering Programs', *40th Annual SEFI Conference*, Thessaloniki, Greece, 23-26 September, 2012
- [17] Sorby, S.A., and Baartmans, B.J. 'The development and assessment of a course for enhancing the 3-D spatial skills of first year engineering students'. *Journal of Engineering Education*, 89 (2000), 301–307.
- [18] Halpern et al., 'The Science of Sex Differences in Science and Mathematics', *Psychological Science in the Public Interest*, August 2007 vol. 8 no. 1 1-51
- [19] Guest, D., 'The hunt is on for the Renaissance Man of computing'. *The Independent* (London), September 17, 1991
- [20] Bankel et al, 'Benchmarking Engineering Curricula with the CDIO Syllabus', *Int. J. Engng Ed.* Vol. 21 (2005), No. 1, pp. 121-133
- [21] Prince, M. and Felder, R., 'The Many Faces of Inductive Teaching and Learning', *J. College Science Teaching*, Vol. 36 (2000), No. 5
- [22] Prince, M. 'Does active learning work? A review of the research', *J. Eng. Ed.*, 93(3), pp 223–231
- [23] Carleton, T. and Leifer, L., 'Stanford's ME310 Course as an Evolution of Engineering Design', Proc. 19th CIRP Design Conf., Cranfield Univ., 30-31 March 2009., pp. 547-555