Ça ira: The Need for Reform of Engineering Education

Llorens, M
Lecturer
Dublin Institute of Technology
Dublin, Ireland
Email: marisa.llorens@dit.ie

O'Shaughnessy, S
Lecturer
Dublin Institute of Technology
Dublin, Ireland
Email: susan.oshaughnessy@dit.ie

Carr, M
Lecturer
Dublin Institute of Technology
Dublin, Ireland
Email: Michael.carr@dit.ie

Sheridan, D[1]
Lecturer
Dublin Institute of Technology
Dublin, Ireland
Email: domhnall.sheridan@dit.ie

Sorby, S
Visiting Professor, Engineering Education and Innovation Centre
Ohio State University
Cleveland, Ohio, USA
Email: Sheryl@mtu.edu

Bowe, B
Head of Learning Development, College of Engineering & Built Environment
Dublin Institute of Technology
Dublin, Ireland
Email: brian.bowe@dit.ie

Conference Topic: Transforming Engineering Education and Lifelong Learning

[1]Corresponding author

1. INTRODUCTION

The American patriot and printer, Benjamin Franklin, was the first US Ambassador to France, serving from 1776 to 1785. When asked how the American Revolution was progressing, he always replied, Ça ira, ça ira [1]. He probably meant ça va, but his French was a little rough at the edges, a fact that annoyed his fellow American delegate, John Adams [2].

If we ask that question today of most engineering educators about the state of engineering education, what would be the reply? Is it going well, or is it in crisis? Within five years of Franklin leaving France, the phrase became part of the Carillon National, sung by the mobs demanding radical change. Is engineering education heading for such a radical movement?

There are certainly contradictions present. All countries, but especially the member states of the OECD, require a supply of well-qualified engineering graduates to maintain their economic growth rates. Estimates of the required STEM (Science, Technology, Engineering, Mathematics) graduates vary, from a 2012 report by President Obama's Council of Advisors on Science and Technology, that stated that over the next decade, 1 million additional STEM graduates will be needed in the US [3].

The problem is: where will they come from? The gender balance of university students is moving towards a decisive female majority. According to the OECD's 2014 statistics [4], 38% of young people across the 26 OECD countries complete university level education, but of that age cohort, 46% are young women and only 30% are young men.

This has serious implication for engineering. In the United Kingdom, the Women's Engineering Society has compiled some sobering statistics:

- Only 6% of the engineering workforce in the UK is female [5]
- Only 5.5% of engineering professionals are female and only 27% of engineering and science technicians are female [6]
- Only 5.3% of women in the UK are involved in SET compared with 33% of men [7]
- In 2012 nearly 4 out of 5 (79%) of those who took A level physics were male [8]
- Only about half (51%) of female STEM graduates actually go on to work in STEM roles, compared with over two thirds (68%) of male STEM graduates [9]
- In 2011, men were awarded 85% of engineering and technology degrees and 82% of computer science degrees [10]
- In the same year, 83% medical degrees and 79% of veterinary science degrees went to women [11]

This is summed up in the following bar chart [12]:

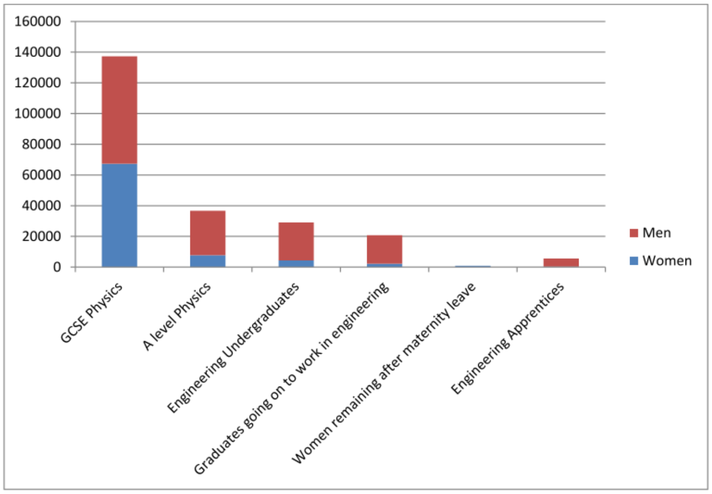

Chart 1: UK Women and Men in Engineering 2014

This phenomenon is not new: it has been developing over decades. Women are choosing certain careers, such as medicine, and are not choosing other careers, such as engineering. We are moving towards a situation where 90% of doctors will be female and 90% of engineers will be male (they already are).

This is bad enough, but the percentage of males getting university degrees is falling, mainly due to poor academic performance in secondary school, almost entirely due to significant differences in reading ability. According to the 2009 PISA assessment of 15 year-olds reading ability, girls outperformed boys by an incredible 39 points across all OECD countries, the equivalent of one year's schooling. [13] The same report notes that boys slightly outperform girls in mathematics, but their overall success, in a school system that is heavily based on reading abilities, holds them back.

This creates a conundrum for engineering educators: female students have the academic qualifications to get into engineering programmes, but lack the desire, whereas male students have the desire, but lack the qualifications. There is a certain amount of denial about all of this. The developments in engineering education in Europe are based on the Bologna Declaration of 1999. This EU document seeks to standardize tertiary education across the EU. The key element for engineering education is the focus on a five years Masters level qualification (MEng) as the minimum requirement for membership of professional engineering institutions. Raising the academic requirements in an era of falling academic standards by male students across Europe seems unlikely to achieve the desired outcome of more and better qualified engineers.

There are two possible solutions to this problem. The first is to persuade a greater percentage of females to take engineering programmes; this has been tried for many decades, with limited success. In fact, most of the 'apparent success' of these programmes is due to the falling numbers of males, rather than an absolute increase in the number of female students. It can also be skewed by inclusion softer engineering disciplines.

This paper looks at the other solution to the problem, the provision of courses to take students who do not meet the required professional level requirements to that point.

2. THE HIGHER EDUCATION SECTOR IN IRELAND

Ireland has seven traditional universities, ranging from the oldest, Trinity College (TCD, founded in1592) to the newest, NUI Maynooth (1997). Then there is the Dublin Institute of Technology, a member of the European Universities Association, with degree awarding powers to doctorate level as well as 13 other Institutes of Technology. There are also small private colleges and other independent colleges.

Admission to higher education in Ireland is via a central office; with access to programmes allocated on the basis of points obtained in the State Leaving Certificate examination (maximum attainable points were 600 over a range of six subjects, now 625 with a bonus for passing the higher level mathematics exams). Qualifications are graded according to a scheme devised by the National Qualifications Authority of Ireland (NQAI). In this scheme, Level 7 is an Ordinary bachelor degree, Level 8 is an Honours bachelor degree, Level 9 is a master's degree and Level 10 is a doctorate.

In this group, DIT has perhaps the most interesting history, having grown organically from a late 19th century group of technical colleges that dealt mainly with craft education, into a degree level institute – initially with degrees awarded by TCD. Since 1993, DIT has been a fully independent institution with degree-awarding powers, covering the full-range of higher education courses, from Level 6 certificates all the way to Level 10 doctorates.

3. THE DIT ENGINEERING STUDENT BODY

The first-year students of Mechanical Engineering in DIT constitute an above average (for level-7 nationally) group of students, with Leaving Certificate entry points typically around 350 (out a maximum possible of 625). In the Academic year 2014-15, the number of students was 60, with an average of 354 points. It is also worth mentioning the overwhelming male bias of the 2014-15 class, with only one female student on the course in that year.

3.1 How Well Do Level 7 Students Do When They Transfer to Level 8?

The key difference between DIT Level 7 and Level 8 Engineering students is mathematics. The Level 7 students do not have the Higher Level Mathematics Grade C that is a requirement for Level 8 Engineering programmes. When they transfer to Level 8, do they sink or swim? The results have been surprising: Level 7 students do well in a Level 8 programme, and even those with little or no Mathematics ability succeed.

For many years, level 7 students had to achieve an upper merit to transfer (60% average in the final exams at level 7). This was reduced to a lower merit (50%) in 2010. We can therefore compare two groups of students, those that met the original higher standard of an upper merit and those more recent graduates with a lower merit.

Table 2 shows a combined analysis for the DIT Mechanical Engineering classes of 2009 and 2010. A total of 85 students who graduated had come from an Honours degree background (i.e. they had entered the programme directly from secondary school), while 33 students graduated who had entered the Honours degree programme from the 3-year Level 7 degree.

Table 2. Level 7 Student Performance in Level 8 in 2009 and 2010

2009 and 2010	Direct Entry (School leavers) to Level 8	Entry via Level 7 course
N	85	33
Average mark (Standard deviation)	53.4 (18.8)	62.1 (8.1)
Number with grade greater than 60%	37 (44%)	27 (81.8%)

The average mark of the direct entry students was 53.4 % with a standard deviation of 18.8. In contrast the students who had entered via the level 7 Ordinary degree had an average of 62.1% with a standard deviation of 8.1%. A two sample t-test was applied to this data and the average mark of the Ordinary degree students was found to be significantly different with p=0.000.

In addition, the proportion of students who achieved an Upper Second (2.1) degree or higher was determined. Of the direct entry students 44% achieved a 2.1 degree or higher in comparison with the Ordinary degree students, of whom 81.8% achieved a 2.1 degree or higher. This difference was found to be significant using two proportion test (p = 0.000) and the Fisher exact test (p = 0.000).

Then, somewhat surprisingly, it was noted that there is little or no correlation between the 3rd year Level 7 mathematics grade and the third year Level 8 mathematics grade with a correlation coefficient of R^2 = 0.139 and p = 0.454, see Table 3 below. The expectation was that students who had successfully completed Level 7 mathematics should be able to adjust easily to the demands of Level 8. The likely explanation is that these students are relaxing in this non-award year after the pressure of the Level 7 degree exams.

Table 3. Correlation between Level 7 and Level 8 Results

Correlation Coefficient (R^2)	3rd Year Level 8 Mathematics R^2 (p value)	4th Year Level 8 Mathematics (p value)	4th Year Level 8 Overall (p value)
3rd year Level 7 Mathematics	0.139 (0.454)	0.533 (0.001)	0.57 (0.001)

This becomes clear when we look at the relationship between the 3rd year Level 7 grade and the 4th year Level 8 grade in mathematics, where there is a strong correlation (R^2 = 0.57) that is highly significant (p= 0.001). There is also seen to be a strong relationship between the 3rd year Level 7 mathematics grade and overall performance in the final year (4th) of the Level 8 honours degree, (R^2 = 0.57, p = 0.001).

Given the strong correlation between the Level 7 mathematics grade and the overall grade in 4th year Level 8, it is clear that the 3rd year Level 7 mathematics grade should be used to select students for entry onto the Honours programme.

Students graduating in 2011 benefitted from the drop in transfer requirement from 60% to 50% in their final level 7 exams. How did this affect their final Level 8 results?

The mean mark on entry was 64.6, with 11 out of 18 having a grade above 60% with the lowest grade 56%.

Table 4. Analysis of Level 7 Transfer students versus native Level 8 Students 2011-13

Year	2011	2012	2013
n (L8 Direct/L7 transfer)	50/18	40/14	65/19
L8 Direct Average Mark (SD)	55 (13.1)	53.9 (13.6)	54.7 (9.4)
L7 Transfer Average Mark (SD)	64.6 (7.07)	60.7 (5.7)	51 (19.45)
Significant Difference between L7 and L8	p = 0.000(t-test)	p = 0.011(t-test)	p = 0.422 (t-test)
L8 Direct with marks above 60	22/50	14/40	38/65
L7 Transfer with marks above 60	8/18	5/14	9/19
Significant Difference between L7 and L8	p = 1 (Fisher's exact)	p = 1(Fisher's exact test)	p = 0.439(Fisher's exact)
L8 Direct Graduated on time (Complete pass)	45/50	35/40	54/65
L7 Transfer Graduated on time (Complete pass)	16/18	13/14	17/19
Significant Difference between L7 and L8	p = 1(Fisher's exact)	p = 1 (Fisher's exact)	p = 0.723(Fisher's exact)

In 2011, even though the threshold for transfer to the Honours degree has been reduced, students from a level 7 background outperform the students who entered directly onto the level 8. This time there is no significant difference between percentage of Upper Seconds or the percentage who graduated on time.

For the class of 2012, only 14 students progressed with 50% having achieved a mark of greater than 60%. The overall average on entry was 60.75% and the lowest mark was 53 %.

Table 5. Correlations between Final Level 7 Maths, Third Year Level 8 Maths, Final Year Level 8 Maths grade and Final Year Level 8 Overall results 2011-13

Correlation	2011	2012	2013
Final Year L7 Maths with 3rd Year L8 Maths R^2 and (p-value)	0.6(0.008)	0.323(0.259)	0.714(0.001)
Final Year L7 Maths with 4th Year L8 Maths R^2 and (p-value)	0.54(0.03)	0.684(0.010)	0.51(0.03)
Final Year L7 Maths with 4th Year L8 Overall mark $R^2$and (p-value)	0.19(0.45)	-0.08(0.771)	0.36(0.13)
Final Year L8 Overall mark with Final Year L7 Overall mark R^2 and (p-value)	0.101 (0.69)	0.22 (0.45)	0.35 (0.134)
Final Year L8 Overall mark with L7 project $R^2$and (p-value)	0.012 (0.96)	0.098 (0.739)	0.174 (0.477)

By 2013 the average mark (57% v 65% in 2011) of ordinary degree students who transfer has been significantly reduced to the point where there is now no significant difference between the performance of these students in terms of overall mark, percentage of Upper Seconds and the percentage who graduate on time.

5. CONCLUSIONS

This project is only beginning, and the data obtained so far is limited. It is intended to build on this over the next few years. But the results are interesting, and quite counter-intuitive. Students delineated as weak at school-leaving, particularly in mathematics, and not of sufficient standard for a professional engineering course end up out-performing their allegedly better colleagues at the end of a Level 8 engineering programme. Even when the bar is lowered, and students with weaker results are allowed to transfer, they still do as well as those who entered directly, with the ‘proper’ qualifications in mathematics.

Over the years, these level 7 transfer students have gone on to successful careers as professional engineers. They graduate with as good as, or better, degree classifications as those who entered with the level 8 requirements directly. It is worth emphasing that none of these excellent engineering graduates would have been given a place in any of Ireland’s more traditional universities.

This raises two important questions for engineering education: firstly, as the world needs more and more engineers, why not broaden the entry pool by formally accepting such students onto a programme that will deliver the required mathematical standard? And secondly, why build a higher education system for the 21st century on an 11th century model that was only ever designed for a small elite?

A good engineer designs the product to suit the person, and does not try to change the person to fit the product. Engineering educators should do likewise! Ça marche.

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