INTRODUCING INDEPENDENT THINKING AND PROJECT SKILLS TO FIRST YEAR ENGINEERING STUDENTS

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1 INTRODUCTION

There is an old Latin aphorism, *poeta nascitur, not fit* (a poet is born, not made), which would seem to argue in favour of nature over nurture in the question of creative ability. Such doubts have not stopped many colleges offering courses in creativity. In 1970, the University of East Anglia began offering an MA in Creative Writing, directed by Malcolm Bradbury and Angus Wilson. The list of alumni includes many award-winning writers such as Ian McEwan, Kazoo Ishiguro, Anne Enright and Tracey Chevalier. Clearly, UEA feels that it is possible to build on innate creativity and develop it to a high standard.

It may seem strange to consider such issues in the context of engineering education, but a good engineer is a creative one, although that creativity may be more technically focused than a Booker prize-winning novel. This is an important issue, because there is always a danger in technical education that facts dominate; the spirit of Dickens' Mr Gradgrind is never far away:

"Now, what I want is, Facts. Teach these boys and girls nothing but Facts. Facts alone are wanted in life. Plant nothing else, and root out everything else. You can only form the minds of reasoning animals upon Facts: nothing else will ever be of any service to them." [1]

Patrick Pearse, the early-20th century Irish educationalist, described the second-level educational system in his 1913 book, *The Murder Machine*. Pearse was scathing in his view of the system: *"Our common parlance has become impressed with the conception of education as some sort of manufacturing process. Our children are the 'raw material'; we desiderate for their education 'modern methods' which must be efficient but cheap; we send them to Clongowes to be 'finished'; when finished they are 'turned out'; specialists 'grind' them for the English Civil Service and the so-called liberal professions; in each of our great colleges there is a department known as the 'scrap-heap' though officially called the Fourth* Preparatory—the limbo to which the debris ejected by the machine is relegated." [2].

Pearse believed, perhaps naively, that an Irish state would provide a system that was truly educational, leading children into knowledge and self-understanding, rather than trying to fill their minds with a prescribed list of useful facts. It is ironic that one hundred years later, as Ireland prepares to celebrate the centenary of Pearse's death, that the current system is little different from that he so despised. The race for Leaving Certificate points has replaced the Civil Service race, as schools attempt to cram the necessary facts into young minds in order that they might maximise their points and so gain admission to the third-level course of their choice.

Indeed, the second-level system of regimented learning is now moving forward into third-level, where once autonomous institutions are being bullied by government into training a new generation to meet the needs of the economy, rather than educating them to live as full citizens of the 21st century. The original idea of a liberal education is being replaced by a utilitarian training programme.

The liberal ideal was expressed in early Victorian times by John Henry Newman, the founder of the Catholic University in Dublin, which would later evolve into University College Dublin, Ireland's largest university.

"I am asked what is the end of University Education, and of the Liberal or Philosophical Knowledge which I conceive it to impart: I answer, that what I have already said has been sufficient to show that it has a very tangible, real, and sufficient end, though the end cannot be divided from that knowledge itself. Knowledge is capable of being its own end. Such is the constitution of the human mind, that any kind of knowledge, if it be really such, is its own reward." [3].

It is especially important in educating young engineers for the 21st century, that the values of a liberal education, with a focus on general principles rather than current preoccupations, is maintained as a paramount virtue. No one wants engineers who only understand vacuum tubes in a transistor age. It is impossible to predict where technology will be in 10, 20, or 30 years time, yet this is the timeframe for our current engineering students, who will still be practising in 2050. The best that can be done is to provide them with the basic knowledge and problem solving-skills that will enable them to engage in a process of life-long learning into the future.

In terms of Bloom's 1956 cognitive taxonomy (Figure 1), most second-level education focuses on the bottom rungs, knowledge and comprehension. The danger is that third-level too, will focus on these levels, with perhaps an attempt at application and analysis.

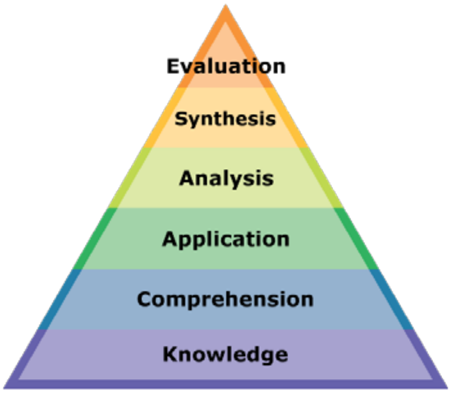

Figure 1

This will lead to a generation of engineers able to solve today's problems, but lost when that technology is inevitably replaced. At the heart of an engineer's skill set is to design; but whereas any competent engineer can design a variation on a theme, it is the ability to imagine the new, the previously unimagined that is the key to future success. This ability to see beyond is captured in Robert Kennedy's favourite quote from Bernard Shaw: *"I dream things that never were; and I say, "Why not?"* [4].

Design is a complex set of related things, but at its heart is the ability to creatively solve problems. The element of creativity is most at risk when programmes focus on the application of technical skills, such as mathematics, but neglect the free-thinking needed for innovative design. As Clive Dym puts it:

"Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints." [5].

Harlim and Belski examine the stages of problem solving: *"It is well-established that problem solving requires a number of key steps: (i) understanding the problem, (ii) planning, (iii) execution and (iv) re-evaluation. Therefore, good problem solvers are expected to possess well-developed abilities to identify and analyse a problem, select and organise relevant information, represent the problem, translate relevant information towards finding a solution, identify one or more solution strategies as well as to apply and evaluate these strategies...*

Problems encountered by engineers in their day-to-day activities are ill-defined and answers are seldom right or wrong. Engineering problems are complex and require creative solutions. Engineers are expected to be capable of identifying technical nature of the problem, achieving a solution and also evaluating the impact of the solution to a whole system/environment." [6]

The current project aims to allow students to work collaboratively on an open-ended problem, one that requires core engineering skills, the ability to estimate outcomes, and the judgement to identify the key parameters. This innovation came about during Louis Bucciarelli's time as Visiting Professor at DIT, during the second semester of 2009. Professor Bucciarelli of MIT is an acknowledged expert in this area (Designing Engineers, Louis L. Bucciarelli, MIT Press, 1996).

2 BACKGROUND TO THE GROUP

The students in this project were first-year level-7 degree students on Ireland's Qualification framework, where level-7 is an ordinary degree, level-8 an honours degree, level-9 a masters, and level-10 a doctorate.

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 600). In the Academic year 2011-12, the number of students was 83 and in the academic year 2012-13, the number was 94. It is also worth mentioning the overwhelming male bias of the 2012 and 2013 classes, with only three female students on the course in each year.

The students study a range of modules: Mathematics, Physics (Integrated Principles of Technology and Heat and Energy), Mechanics and Materials, Instrumentation, Professional Development, Workshop Processes, Drawing and Computation.

One of the aims of this project, in addition to the open design element, was to try and integrate material from a number of the modules, so that students would see that the material from the different modules formed an integrated whole, rather than as isolated pieces of knowledge.

3 OPEN DESIGN PROJECT DETAILS

The original exercise devised by Professor Bucciarelli was based on verifying the law of friction using an excel spreadsheet to simulate the problem. This exercise was done in isolation up to and including 2012. It was felt, however, that the exercise was a little too challenging for first-year students, without any prior experience of such techniques. Therefore, in the 2013 academic year, a preliminary exercise, based on a simpler, single-session exercise on the Gas Laws, was introduced in the middle of the second semester, in order to prepare students for the Friction exercise at the end of that semester.

The introductory exercise required students to calculate the spring constant needed for an emergency release valve on a gas pressure vessel. The students were broken into groups of four, and were given a short presentation and handout on the problem. They had two hours in the lab, with assistance from two lecturers, and then had to email their solution, in the form of a Word document and an Excel spreadsheet by 5 p.m. the following day. Given the numbers involved, the exercise was run four times, with around 16-18 students per session.

The second exercise was run over two weeks, also in a two-hour lab session. The problem posed was "To set up an experiment to verify the equation $F_s = \mu_s N$". In preparation for this exercise, most of the relevant knowledge for this problem had been covered earlier in the semester in both mechanics and physics. The students were given a two-page handout giving the background theory, and a list of functional requirements and outputs. They were told that an excel spreadsheet was to be set up to evaluate the frictional force for different materials across various experimental setups. Students were informed that they had to explain and justify their choices and final recommendations.

The exercise was open-ended and students were given the freedom to go into as much detail as they wished within the time provided. The exercise proved to be challenging for many of the students, who were more used to well-defined laboratory work. The good students rose well to the challenge, producing a wide variety of interesting and satisfactory designs that met the brief.

At the end of the second session, the teams were given one week to write up the report and submit it, along with the excel spreadsheet that they had designed.

4 GENERAL OBSERVATIONS ON THE EXERCISE

1. The exercise required the students to utilize a wide variety of knowledge from their different modules.

2. The open-ended nature of the exercise sets a research-like context. Students are encouraged to search the web for relevant information, to explore possible “solutions”, to critique the proposal in the first place, even to offer alternatives.

3. Students are active; furthermore, the openness gives the more advanced students the opportunity to go ahead while, at the same time, those less prepared are challenged at their level. The class does not proceed “lock-step”.

4. Monitoring the students work while responding to their questions in process reveals lacunae in their understanding without passing judgement.

5. Students learn something about engineering design process, its iterative nature, how theory underpins building a product, the necessity of tradeoffs.

5 SURVEY RESULTS

Students were surveyed at the start and at the end of the introductory exercise (in 2013). They were surveyed three times during the main exercise, at the start, just after the presentation of the theory and requirements of the design problem and at the end of this first lab session (in both 2012 and 2013). The third survey was done the following week, at the end of the lab sessions. Between 32 and 50 students completed all surveys and their answers are analysed below.

Tables 1, 2 and 3 show the results of a Likert questionnaire on the students’ perceptions of the exercise in 2012. Table 1 shows the responses at the end of the initial presentation of the task. Table 2 records the students’ responses at the end of the first 2-hour session. Table 3 shows the responses at the end of the second session on the following week.

Table 1. Start of First Session 2012 (n = 50)

Question	Mean
Clarity of presentation, 1 not very to 5 very clear	2.83
Clarity of handout, 1 not very to 5 very clear	3.21
My understanding of what I have to do, 1 poor to 5 excellent	2.65

Table 2. End of First Session 2012 (n = 50)

Question	Mean
My progress, 1 little to 5 loads	2.52
Teamwork, 1 poor to 5 great	4.24
Difficulty of session, 1 low to 5 high	3.20

Table 3. End of Second Session 2012 (n = 50)

Question	Mean
My understanding of what I have to do, 1 poor to 5 excellent	3.37
My progress today, 1 little to 5 loads	3.68
Teamwork, 1 poor to 5 great	4.27
Difficulty of exercise, 1 low to 5 high	3.13
I enjoyed the exercise, 1 agree to 5 disagree	2.9
I enjoyed the challenge, 1 agree to 5 disagree	3
I learnt a lot from the exercise, 1 agree to 5 disagree	3.2
I would have preferred more guidance, 1 agree to 5 disagree	2.89
I would prefer more structure to the exercise, 1 agree to 5 disagree	2.74
I understand better the conflicting problems of engineering projects, 1 agree to 5 disagree	2.44
My engineering skills have improved, 1 agree to 5 disagree	2.66

Table 4 is from the beginning of the new introductory exercise which was run in March 2013. Again, the students' responses were recorded on a Likert questionnaire.

Table 4. First Introductory Session 2013 (n = 44)

Question	Mean	Median	Mode
Clarity of presentation, 1 not very to 5 very clear	2.51	3	3
Clarity of handout, 1 not very to 5 very clear	2.77	3	3
My understanding of what I have to do, 1 poor to 5 excellent	2.85	3	3

Tables 5 and 6 are from the end of the introductory exercise and from the end of the main exercise (run in April 2013). Similar questions were asked (apart, of course, from their perceived difficulty of the main exercise), and are shown in two columns.

Table 5. End of First Introductory Session and end of Main Session 2013 (n = 44 and 32)

Question	Mean (Intro)	Mean (Main Exercise)
My understanding of what I have to do, 1 poor to 5 excellent	3.58	3.61

My progress today, 1 little to 5 loads	3.33	3.79
Teamwork, 1 poor to 5 great	3.63	3.75
Difficulty of introductory exercise, 1 low to 5 high	3.53	3.24
Difficulty of main exercise, 1 low to 5 high	-	3.59
Difficulty of lab programme, 1 low to 5 high	3.03	3.06
I enjoyed the exercise, 1 agree to 5 disagree	3.02	3.00
I enjoyed the challenge, 1 agree to 5 disagree	3.02	2.87
I learnt a lot from the exercise, 1 agree to 5 disagree	3.37	3.37
I would have preferred more guidance, 1 agree to 5 disagree	2.86	2.63
I would prefer more structure to the exercise, 1 agree to 5 disagree	2.43	2.78
I understand better the conflicting problems of engineering projects, 1 agree to 5 disagree	2.49	2.77
My engineering skills have improved, 1 agree to 5 disagree	2.62	2.93

5.1 Investigation of a change in response between the two sessions, using the Mann-Whitney U test.

A key concern of the survey was to ascertain as to whether, or not, any change occurred in the students' understanding of the core problem between the sessions. In 2012, this was simply between the two sessions of the exercise; in 2013, it was between the beginning and end of the introductory exercise and between the beginning and end of the main exercise.

In order to test for a statistically significant difference between the mean understanding in week one and that in week two, the Mann–Whitney U test, a non-parametric statistical hypothesis test for assessing whether one of two samples of independent observations tends to have larger values than the other, was used.

Year	Question	z-value	P (2-tail)	Null Hypothesis
2012	Understanding	3.726	0.000104	Reject
2013	Understanding 1	3.338	0.000106	Reject
2013	Understanding 2	1.574	0.1154	Accept
2013	Guidance	0.898	0.368	Accept

In general, there was a statistically significant increase in understanding in 2012 and 2013 between the start and end of the sessions. No statistically significant change was observed in 2013 between the start and end of the second, main, exercise.

Having said that, it could be argued that whereas the z-value for the understanding question on the main exercise in 2013 was below the 5% confidence threshold of 1.96, at 1.57, and the p-value was twice that for significance (0.1154 > 0.05,), it was not insignificant. It is possible that for the 2013 students, the shift in understanding occurred with the first exercise, and therefore only to a limited extent with the second.

6 SUMMARY

The American writer H.L. Mencken (1880-1956) wrote that “there is always a well-known solution to every human problem—neat, plausible, and wrong.” (Prejudices: Second Series, 1920) There is no simple solution to the rote-learning and cramming techniques used by students to obtain the entrance points for Irish third-level education. There are options for third-level educators who want to try and change these habits. One of those options is to challenge students with the sort of problems and exercises that are the opposite of those encountered at second-level. This issue is by no means confined to Ireland, and is a challenge for educators everywhere. For example, Louis Bucciarelli’s latest book, *Engineering Mechanics for Structures* (Dover, 2008) uses open-ended examples and problems to try and inculcate students with the reality that there are many solutions to engineering problems, and the skill of an engineer is in finding the optimal one, given all the constraints, such as financial, time, regulatory etc.

The results of this exercise, on its fifth iteration, are generally positive. The Mann-Whitney analysis reveals a clear change in the level of understanding between the first and second sessions in 2012, and between the beginning and the end of the introductory session in 2013. The fact that there is no significant change between the first and second sessions of the main exercise in 2013 may be due to the prior shift during the introductory exercise.

The questions relating to the students’ enjoyment of the challenge were generally positive, with mean values of 2.9 in 2012 and 3.0 in 2013. The students did not express a strong preference for more guidance and structure, with mean values of 2.89 in 2012 and 2.63 in 2013 for this question, but in their comments, the largest percentage, 36%, did ask for more guidance, hardly surprising for first-year students, more used to highly-directed activities.

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