THE EFFICACY OF A CDIO BASED INTEGRATED CURRICULUM AS PREPARATION FOR PROFESSIONAL PRACTICE IN PRODUCT DESIGN AND DEVELOPMENT

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ABSTRACT
The School of Mechanical and Aerospace Engineering at Queen's University Belfast started BEng and MEng degree programmes in Product Design and Development (PDD) in 2004. Intended from the outset to be significantly different from the existing programmes within the School the PDD degrees used the syllabus and standards defined by the CDIO Initiative as the basis for an integrated curriculum. Students are taught in the context of conceiving, designing, implementing and operating a product. Fundamental to this approach is a core sequence of Design-Build-Test (DBT) experiences which facilitates the development of a range of professional skills as well as the immediate application of technical knowledge gained in strategically aligned supporting modules.
The key objective of the degree programmes is to better prepare students for professional practice. PDD graduates were surveyed using a questionnaire developed by the CDIO founders and interviewed to examine the efficacy of these degree programmes, particularly in this key objective. Graduate employment rates, self assessment of graduate attributes and examples of work produced by MEng graduates provided positive evidence that their capabilities met the requirements of the profession. The 24% questionnaire response rate from the 96 graduates to date did not however facilitate statistically significant conclusions to be drawn and particularly not for BEng graduates who were under represented in the response group. While not providing proof of efficacy the investigation did provide a good amount of useful data for consideration as part of a continuous improvement process.

Keywords: CDIO, graduate attributes, preparation for professional practice

1 INTRODUCTION

The introduction of a new degree programme inevitably raises many questions regarding how effective it is in delivering the intended learning outcomes for its graduates. If the structure of the programmes is also based on the syllabus and standards of an innovative approach to engineering education, namely CDIO [1], then there is a desire to demonstrate the efficacy of the approach to those involved locally. The results are also likely to be of interest to the CDIO and engineering education communities at large.
Efficacy by definition does however imply certainty and this presents a significant challenge. With BEng programmes taking a minimum of three years and MEng programmes four years to produce graduates there is an unavoidable delay before it is possible to even start to measure graduate attributes. There is also the issue of being able to gather a large enough sample to be able to determine statistically significant conclusions. With an average of 20 students graduating from the programmes each year there is inherently a limit to the degree of certainty that might be gained after just 5 years of graduating cohorts. It is however better to have some rather than no information on which to base decisions on how such a new programme might be developed and refined and on this basis an investigation of graduates as described in this paper was undertaken.
The PDD degree was developed shortly after the School of Mechanical and Aerospace Engineering at Queen's University Belfast joined the CDIO initiative in 2003, as one of the early adopters of this methodology, enrolling its first students in September 2004. The objective was to create a degree which had a different focus and approach from the existing engineering programmes in the School and which adopted the 12 standards defined by the original collaborators (MIT, KTH, Linkoping and

Chalmers) as to how a modern engineering curriculum should be structured and delivered. At the core of the programme is an integrated curriculum [2] (CDIO standard 3) which enables engineering design to be taught in the context (standard 1) of conceiving, designing, implementing and operating a product. This is achieved by a series of Design-Build-Test projects (Standard 5) which facilitate the immediate application of knowledge and skills gained in strategically aligned and scheduled modules. Other standards relate to non-curricular aspects of the programme such as the enhancement of faculty teaching skills (standard 10) and the requirement to reflect and evaluate the programme on a regular basis (standard 12). The active and interactive learning approach (standard 8) adopted by the project and the problem based curriculum is geared towards producing graduates ready for professional practice, not engineering science researchers. With a broader range of A-Level subjects accepted as entrance qualifications and a broader curriculum, covering more of the conceptual as well as the business end of new product development than a traditional engineering degree, it was likely that a slightly different type of graduate would be produced. If fact the objective is to produce the type of graduates employers want, as determined from a comprehensive stakeholder survey carried during the development of the CDIO syllabus and standards [3]. This survey gathered the opinions of employers, early career and senior graduates as well as engineering faculty members as to the skills and attributes required of a 21st century graduate engineer to practice professionally. The CDIO collaborators were not unique in undertaking such an investigation and several similar studies have been carried out both before and since, for example the American Society of Mechanical Engineering Vision 2030 [4]. The CDIO collaborators have continued to work to refine the methodology over the last decade and the community has grown to around 100 institutions, spread across the globe, who meet biannually to collaborate and share best practice.
What follows is an attempt to determine what has happened to the graduates from the PDD programme thus far. Are they gaining employment in the discipline they are being trained for and are their skills and abilities on graduation of the level required for their profession?

2 PDD GRADUATE SURVEY

Between 2007 and 2012 there have been 96 graduates from the PDD degrees, 47 with BEng qualifications and 49 graduating with MEng degrees. MEng PDD graduates typically study more engineering science than their BEng counterparts. Their 4th year of study includes modules on advanced materials and computer-aided-engineering analysis as well as an industrial placement project or a semester of study abroad. Each cohort has been routinely surveyed 6 months after graduating in order to produce employment rate statistics. Table 1 shows the collated returns from these surveys, complemented by updated data received through ongoing contact between the graduates and faculty members of the School.

Table 1. Employment status of PDD graduates 2007 - 2012

	BEng	MEng	Total (% of total)
Graduates	47	49	96
PDD Graduate employment	23	45	68 (71%)
Non-graduate employment	7	2	9 (9%)
Status not known	17	2	19 (20%)

In this study graduate employment is defined as being directly related to the PDD discipline. For example retail management was not included, even if the post required a degree level qualification. While the overall level of graduate employment at 71% is comparable to the other degrees in the School, and across the UK, it is noticeable that the level of confirmed BEng graduate employment is significantly lower than that of MEng graduates. The large number of BEng graduates whose employment status is unknown does not enable an accurate picture for this group to be determined. If it is assumed that a graduate who has been unable to find a graduate level job during the survey period is unlikely to respond then the accurate employment rate for BEng students is realistically unlikely to be much higher than the 49% shown. A 92% graduate employment rate among the MEng group is significantly higher that the UK engineering and technology sector average of 73% as reported in 2012 by the Higher Education Statistics Agency [6].

The breadth of the curriculum and the more generalist nature of the PDD degree has resulted in the graduates being employed in a wide range of design and engineering sectors as detailed in Figure1. While a large number of respondents indicated a job title including the phrase “design engineer” these have been subdivided into categories depending on the nature of the products produced by their employers. The consultancy category refers to graduates working for what are commonly called “design houses”. Of the 9 graduates who have gone on to train as secondary level Design & Technology teachers, by studying for a Post Graduate Certificate of Education (PGCE), 8 were BEng graduates.

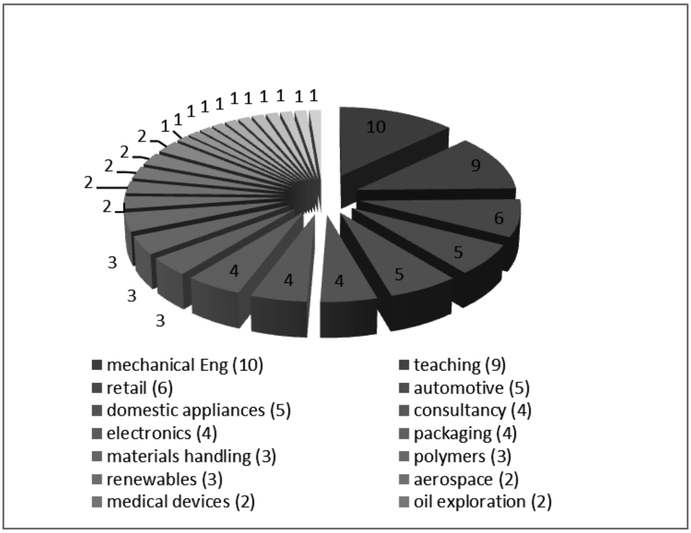

Figure 1. PDD graduate employment by sector

2.1 PDD graduate responses to MIT stakeholder survey

Those identified as being in graduate employment were emailed a copy of the stakeholder survey questionnaire used by MIT in the original CDIO syllabus report of 2002 [3]. Graduates were asked to self-assess their level of proficiency, using a set of descriptors (Table 2), in a range of learning outcomes covering the generic sections 2 to 4 of the CDIO syllabus [1].

Table 2. Stakeholder survey – level of proficiency descriptors

1	To have experienced or been exposed to
2	To be able to participate in and contribute to
3	To be able to understand and explain
4	To be skilled in the practice or implementation of
5	To be able to lead or innovate in

From a pool of 68 in graduate employment 16 completed questionnaires were returned, representing a 24% response rate. It should be noted however that the profile of the returns means that these self-assessments cannot be considered representative of all graduates of the PDD degrees. 15 of the 16 returns were from MEng graduates and 11 were from graduates with 1st class degrees.

Table 3 shows the average and standard deviation of the responses received in each of the 13 categories. These responses have been compared to results of two previous surveys using the same tool carried out by the Department of Aeronautics and Astronautics at the Massachusetts Institute of Technology (MIT) in 2001 and the School of Mechanical and Aerospace Engineering at Queen’s University Belfast (QUB) in 2003 (Figure 2). It should be noted that the previous studies also included employers, faculty members and senior engineers as well as early career graduates. While the trend of the responses from PDD early career graduates (peaks and troughs on Figure 2) is similar to both of the previous studies the absolute scores are close only in 4 of the 13 categories. In all other cases the PDD graduate average scores are significantly higher.

Table 3. PDD graduate stakeholder survey responses

	average	SD
2.1 ENGINEERING REASONING AND PROBLEM SOLVING	4.1	0.68
2.2 EXPERIMENTATION AND KNOWLEDGE DISCOVERY	3.2	0.77
2.3 SYSTEM THINKING	3.4	0.73
2.4 PERSONAL SKILLS AND ATTRIBUTES	4.2	0.58
2.5 PROFESSIONAL SKILLS AND ATTITUDES	3.8	0.77
3.1 TEAMWORK	4.3	0.58
3.2 COMMUNICATIONS	4.3	0.68
4.1 EXTERNAL AND SOCIETAL CONTEXT	2.6	0.73
4.2 ENTERPRISE AND BUSINESS CONTEXT	3.4	0.73
4.3 CONCEIVING AND ENGINEERING SYSTEMS	4.1	0.68
4.4 DESIGNING	4.4	0.63
4.5 IMPLEMENTING	3.5	0.73
4.6 OPERATING	3.5	0.82
	3.75	

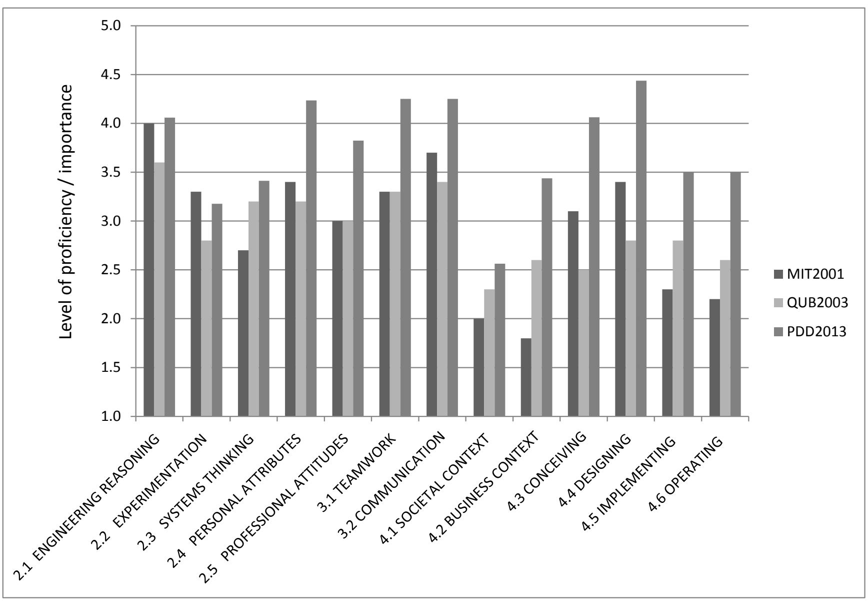

Figure 2. Comparison of PDD graduate responses to MIT and QUB stakeholder surveys

It would be tempting to stop the analysis at this point, congratulate everyone for a job well done and state that the PDD programme clearly delivers on its intended learning outcomes. The data however is not representative since it has come only from the upper quartile of the graduates and there is of course also the possibility that the graduates have overestimated their abilities. This might be a reasonable assumption but it has been shown by Kruger and Dunning [5] that the opposite can in fact be the case and that it is the very brightest students who, if anything, tend to underestimate their own ability. Overestimation is a characteristic more commonly found among the less able members of a cohort, which is not the profile of the students returning the questionnaires in this survey. The sample size is however is still too small to be statistically significant so, while encouraging, these results alone are not conclusive.

The second part of the survey asked for more specific consideration at the next level of detail in the CDIO syllabus. Here the graduates indicated where more emphasis might be placed in a subtopic, over its higher level category, to match the needs of the discipline in industry. They were also asked to identify corresponding subtopic areas where less would be sufficient. At this level of detail there were some subtopics where all respondents agreed but others where opinions were split. Figure 3 shows a sample of the returns at this subtopic level with red (-1) cells showing the number of respondents suggesting less emphasis and green (1) cells representing respondents suggesting more in this subtopic.

4.1 EXTERNAL AND SOCIETAL CONTEXT																			
4.1.1 Roles and Responsibility of Engineers	0.0							-1	-1	-1	1	1	1						
4.1.2 The Impact of Engineering on Society	0.6									-1	1	1	1	1					
4.1.3 Society's Regulation of Engineering	-1.0					-1	-1	-1	-1	-1									
4.1.4 The Historical and Cultural Context	-0.8			-1	-1	-1	-1	-1	-1	-1	1								
4.1.5 Contemporary Issues and Values	1.0										1	1	1	1					
4.1.6 Developing a Global Perspective	1.0										1	1	1	1					
4.4 DESIGNING																			
4.4.1 The Design Process	-0.2							-1	-1	-1	1	1							
4.4.2 The Design Process Phasing and Approaches	-1.0					-1	-1	-1	-1	-1									
4.4.3 Utilization of Knowledge in Design	0.7									-1	1	1	1	1	1	1			
4.4.4 Disciplinary Design	-0.2							-1	-1	-1	1	1							
4.4.5 Multidisciplinary Design	-0.2							-1	-1	-1	1	1							
4.4.6 Multi-Objective Design (DFX)	0.0								-1	-1	1	1							

Figure 3. Examples of collated subtopic level responses regarding relative emphasis

2.2 PDD graduate interviews

In order to gain further insight into the survey results telephone interviews were conducted with 4 MEng graduates from the 16 respondents. The graduates selected were known to have produced exemplary professional work which was within the intended scope of graduates from the PDD programme (Figure 4). The interviews were structured around the questionnaire which had already been returned and asked for clarification and expansion regarding scoring patterns, primarily at the subtopic level.

Figure 4. Examples of PDD graduate professional work (left to right): Fastap tap stand (Fast Engineering), Koolite GAA helmet for O'Neills (ID Product Development), space heater (Whale)

The interviewees unanimously endorsed the project based curriculum as an effective means of developing the skills and attributes required of professional practice. Several suggested that this might even be "pushed further" by including links to more engineering science modules at the same time and by introducing unexpected design specification changes mid-project, to mimic their real world experiences. It was also suggested that more individual and shorter concurrent projects would more accurately reflect working practice and would further broaden the experience and skills that could be developed with this kind of study. Those with industrial placement experience singled this out as the "icing on the cake" in terms of being able to apply and bring together all of their acquired skills and knowledge. There were also a number of comments recommending more extensive workshop and prototyping facilities for student use that would encourage "discovery by experimentation" as well as developing useful "hands on" practical skills.

Clarification on the relatively low scoring for the external and societal context category revealed that teaching faculty are seen as being somewhat lacking in experience of application in a commercial environment and the “uncertainty” and “curve balls” of the real world contrasted with the certainty of some of the teaching. Best practice specialist software analysis tools available in the university were highlighted as not being within reach of smaller companies and this had limited the ability of some graduates to apply all they had learned. Confidence was brought up as a positive characteristic by more than one graduate, linking this to the breadth of the degree, “solid engineering fundamentals” and highly developed critical thinking and problem solving skills.

The issues raised through interview have both endorsed the format and content of the MEng programme and provided a number of suggestions for further enhancement of both the curriculum and faculty teaching skills (CDIO standard 10).

3 CONCLUSIONS

Graduate employment statistics, questionnaires and structured interviews were effectively used to gather information to assess the efficacy of a recently established degree programme.

The evidence supporting the efficacy of the MEng PDD programme as preparation for professional practice was strong but the small sample size means this cannot be considered statistically significant. There was an inherent problem in obtaining a statistically significant and representative sample from a programme which started in 2004 with only 20 graduates per year, compounded by the varied rate of response observed from the students on the bachelor and masters pathways. Irrespective of this valuable insights were gained from the investigation. The fundamental approach of a DBT core to the curriculum was widely endorsed. BEng graduates were observed to have lower rates of employment than their MEng counterparts in jobs requiring their degree qualification. A number of graduate generated suggestions for further enhancements to the degree programmes content and delivery were also obtained.

The stakeholder survey evaluation tool used provides a standardised means of comparing graduate attributes against those of other degree programmes, whether CDIO based or not. Within the engineering education community similar investigations could provide data to further evaluate the efficacy of current undergraduate teaching practice.

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