Educating Engineering PhDs to be Innovative and Entrepreneurial:
A Cross-disciplinary initiative

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INTRODUCTION

It is widely accepted that the academic career path is now an option only available to the minority of PhD graduates in Engineering today [1]. The vast majority of Engineering PhD students will progress to a career in industry where 'non-technical' skills (such as communication, the ability to adapt to change, teamwork and leadership) are of considerable value, in addition to the technical discipline specific skills obtained in their field of research [2].

As such recent efforts have focused on bringing a breadth to PhD programmes while retaining the technical depth and original contribution to knowledge of each individual research dissertation [3]. Structured PhD programmes including a career development component are fast becoming the norm in PhD Education across the disciplines [1]. The Salzburg Principles from 2005 outline that Universities have a responsibility to provide career development opportunities for PhD students [1]. Indeed the Salzburg II Recommendations in 2010 [4] highlight that main outcome of doctoral education as an early-stage researcher with specific research and transferable skills as opposed to just the research results contained in the thesis. Visualised differently, the goal is to create "T-shaped" researchers who have deep knowledge in one or two domains, and broad expertise and communications skills in related areas [7].

Transferable skills have been defined as skills learned in one context (e.g. research) that are useful in another (e.g. business, future employment, etc). Transferable skills may be developed through training or work experience. It has been found that bringing together PhD students from differing disciplines and at differing levels of completion is the best approach to achieving this development, encouraging inter-disciplinary dialogue and innovation [5]. Examples of such programmes include inter-institutional and international summer schools or specialised institutional or inter-institutional support/personal development centres [5, 6] (e.g. the UK GRAD programmes and the TCD-UCD Innovation Academy in Ireland).

Innovation and entrepreneurship are key transferable skills which are considered vital to preparing Engineering PhD students for careers in industry [7]. In the UK and Ireland at national level, PhD graduate skills statements have been developed which outline what skills doctorate holders can be expected to possess [8]. Skills in the areas of innovation and entrepreneurship include: an understanding of the role of innovation and creativity in research; an appreciation of intellectual property (IP) issues; an understanding of knowledge exchange; the ability to develop entrepreneurial enterprises; and an understanding of different cultural environments such as in the business and academic worlds.

Innovation and Entrepreneurship Education has been identified as a mechanism through which investment in education can generate economic and societal returns (i.e. job creation) in a knowledge based economy [9]. Previous research has highlighted the need for engineers to possess 'business, social and interpersonal' skills to operate effectively in the environments in which they work [10]. Students need, not only to learn about entrepreneurship, but also to have a strong understanding of the interaction between technology, markets, people and finance. Such education in transferable skills can play a role in aligning the Graduate Engineer's profile with the requirements to contribute to a knowledge based economy. The argument for a closer alignment of Engineering and Business Education curricula at PhD level therefore is clear.

The European Universities Association has identified the following transferrable skills at doctoral level: communication, acquire & synthesise knowledge, interaction with other disciplines, commercial awareness, and research management [11]. Such an approach to PhD Education has been proposed to improve the employability of graduates as well as their impact on economies. Long standing evidence from Canada supports this proposition, where the impact of innovation and entrepreneurship education was evidenced by 40% of engineering graduates who had received this training starting their own small business [12].

This paper outlines a novel approach to Engineering PhD Education through the development of an Engineering-Business PhD programme. The paper outlines a longitudinal case study with data obtained from student feedback and programme related documentation on the development of the PhD programme. The traditional and new programme approaches to PhD curriculum development, and student supervision are compared. The benefits for the joint Engineering/Business PhD are outlined in terms of graduate attributes, employability, and research quality.

1 THE ENGINEERING-BUSINESS PHD PROGRAMME

1.1 Context

The context in which this educational intervention arose came about as a result of an EU funded research project examining potential improvements in the sustainability of the water industry through hydropower energy recovery, from both Engineering and Organisational perspectives.

The project comprised a number of work packages addressing the technical (engineering), environmental and organisational (business) challenges inherent in the research. The project, like the water industry itself, involved a multidisciplinary mix of Environmental Engineers, Environmental Scientists, Geospatial and Business Specialists (Engineering and Business were to be situated in the same institution (Trinity College Dublin School of Engineering and School of Business). The project team was to include a number of PhD research students associated with each of the work packages involved. The work packages were also to be split between the two collaborating institutions involved.

At the proposal stage, the original project plan included the appointment of Engineering PhD students and Business PhD students. However an alternative approach was taken prior to the commencement of the project. Three Engineering-Business PhDs were appointed instead. In essence each student in their research would address an aspect of the project from both Engineering and Business perspectives. The balance of emphasis on the two disciplines would be set in relation to the deliverables of the project and the strengths and ambitions of the students. It was recognised that this balance would also be required to favour one major discipline in order to ensure that each student could attain and demonstrate a depth of knowledge in a primary field. Correspondingly, the second, and minor, discipline would serve as a complementary area, bringing breadth to the student's knowledge base as well as transferable skills. In the project, Engineering was the primary discipline for the appointed PhD students and Business was the minor discipline. In another project setting, the opposite approach could have been adopted if this was seen as necessary to achieve the research project deliverables.

The motivation behind this new approach was to: i) encourage the development of T-Shaped students, yielding both a technical depth in their main discipline as well as a breadth in the complementary discipline; ii) to reflect the true nature of the Engineering industry which graduates would encounter in practice, requiring a mix of engineering and business skills; iii) to foster deep insights and interdisciplinary collaboration across the Engineering and Business work packages of the project.

1.2 Curriculum Design

The curriculum of the Engineering-Business PhD Programme was developed in line with the concept of the T-Shaped person [7] along with Figure 1. Conceptually the programme comprised an alignment of depth in Engineering research (the web) with breadth in Business research and training (the flange). The T-Shape created can be described in Structural Engineering terms as combining the deep web with broad flange, welded together at some common intersection. As highlighted above in order to ensure sufficient depth as well as breadth in the graduates, the programme was developed to be balanced between the disciplines (75-25% Engineering – Business). The relative emphasis is not exact as there is a conceptual and practical overlap, integration and common ground between the two disciplinary perspectives.

Research and training were inherent to both aspects of this T-shaped integration of disciplines. As a result of the background of the entrants into this programme, all qualified Engineers with industrial experience, only a limited amount of Engineering training would be necessary. Their prime Engineering focus would be on developing research depth.

On the other hand the breadth and transferable skills were to be gained, for the most part, within the Business discipline. As the students entering the programme had little or no background in the domain of Business, a significant proportion of the flange comprised the development of transferable skills such as: commercial awareness, Innovation & Entrepreneurship, interaction with other disciplines and communication skills [11]. These skills were to be complemented by an appreciation of research in organisations. Some of the aforementioned transferable skills could also be attained through the execution of the Engineering research but in a less deliberate and focused manner (e.g. communication skills).

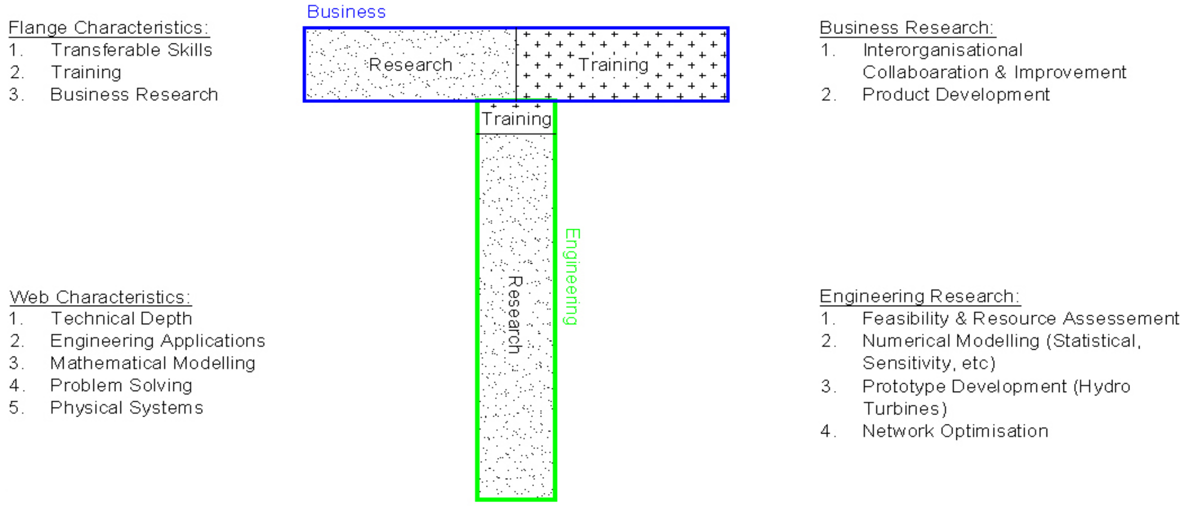

Fig 1. Curriculum Design Concept: The T-Shaped PhD Graduate

The delivery of these transferable skills in the flange comprised a number of approaches. The students enrolled in an inter-institutional, multidisciplinary graduate education initiative within the university, called the Innovation Academy. Here, their education would merit the award of a postgraduate certificate in Innovation & Entrepreneurship [6]. In 2010, Trinity College Dublin and University College Dublin, two of the largest universities in Ireland, developed the Innovation Academy in a response to a perceived need to enable the doctoral student to contribute to knowledge and society in different ways, and to develop within the doctoral researcher new and different skills and perspectives. Training and education is delivered within a multidisciplinary environment, facilitating new ways of thinking and helping to uncover opportunities for commercial or social application of doctoral research.

In addition to this, the students also enrolled in a year-long research methods module run by the School of Business. This module explored the philosophy of science and research methodology from a Business/Social Science perspective. This module was an important element of transferable skills development (e.g. organisational awareness) as well as an enabler for the students to carry out a business or organisational element of their thesis from a business perspective.

Finally the students developed their transferable skills further by each carrying out an element of their thesis work on a business topic related to the central topic: Energy Recovery in Water Infrastructure. As listed in Figure 1, the topics the PhD students focused on were Inter-organisational Collaboration and Improvement as well as on the process of Product Development. Two students examined cases of the implementation of energy recovery projects in the water industry by a group of organisations from an organisational perspective and explored models of collaboration among firms in order to understand choices in future implementation of such projects. The third student, whose Engineering research focused on the development of hydropower turbines for the water industry, examined the process of product development in the water industry where products might find application in both the developing and developed worlds.

In the web of the T, the students' engineering research covered a range of topics related to energy recovery in the water industry such as resource assessment, development of design guidelines, development of network optimisation algorithms, development of new hydropower turbine prototypes, etc. Thematically, their work focused on areas of engineering science such as mathematical modelling, experimentation on physical systems, problem solving and device development.

1.3 Student Supervision

Conveniently, the model of PhD supervision adopted to support the programme also conforms to the T-Shaped individual concept [7]. Figure 2 illustrates the model of joint T-Shaped supervision adopted in this programme. Joint supervision is strongly encouraged at Trinity College Dublin as well as nationally in Ireland and it is considered a necessity for interdisciplinary projects such as the project in this paper [13-14].

Fig 2. Supervision Model: T-Shaped Supervision

Here "Dr. Eng" (the Web) assumed the role of primary supervisor for the students focusing on their technical engineering work, while "Dr. Bus" (the Flange) assumed the role of co-supervisor focusing on the business research and training. Both supervisors regularly met with the PhD students individually to discuss specifics relating to their respective disciplines. However both also met the students jointly on a regular basis to provide oversight to the integration of the perspectives in the project as a whole.

Indeed it is worth noting that the success of the programme in aligning the two disciplines may lie in the common ground between the web and flange as illustrated in Figure 1. While engineering and business are closely aligned in the reality of private industry, they are not natural partners in the University. In this case, however, both supervisors have a primary degree in Engineering, with divergent later degrees at postgraduate level and industrial experience. Both supervisors worked for a number of years in the Engineering industry and as such had obtained transferable skills of their own to allow an understanding of the common ground between the two disciplines, and a sharp awareness of the exploitation of that common ground in the context of the water industry and its energy consumption problems.

As such this common ground allowed for the initial development of a multi-disciplinary project proposal and award of funding. This common ground also allowed for the development of a PhD programme of joint multidisciplinary supervision.

Perhaps another reason for the success of the programme is that the research from both perspectives is grounded in practice as opposed to abstract scholarship. For example the business research examines real organisational dynamics in the water industry and the genesis of real energy recovery projects. The Engineering research is developing tangible outcomes such as prototypes, design guidelines, algorithms etc. Where these Engineering outputs would fit in the business world and how the business world influences the success or otherwise of these outputs is clear to all parties. In the case of an abstract research topic, it may be difficult to identify the common ground and may not be appropriate for the current programme design.

1.4 Student Experience & Industry Engagement

Three students are engaged currently in the programme of study and research. We invited them to reflect on their experience to date and to share their insights with us. We encouraged them to focus on perceived benefits and drawbacks of the combined Engineering-Business approach. Their responses were insightful:

> *'Conducting research which is both Engineering and Business based encourages a more holistic interpretation on a topic; there is a wider variety of considerations, thus making (my) topic more interesting.'*
>
> *'I think any drawbacks are outweighed by the benefits. Of course we must be mindful of the value of specialisation but I don't see this as being exclusive to multidisciplinary learning.'*
>
> *'I have gained and developed many valuable skills that I know will be of great benefit to me with my research project and also with my future working career.'*

These responses were positive and appreciative of the opportunity afforded. They agreed with the underlying premise of the value of a multi-disciplinary approach, in practice and in prospect.

Another indicator of the impact of the approach is the nature of industry engagement with the PhD researchers. Organisations such as IBM, Intel, Welsh Water, Veolia Water and Dublin City Council have engaged actively with the students, providing data, critique and training. For example, IBM accepted one of the students for a three-month internship focused on the optimisation of water supply networks. The internship promised to accelerate the student's up-skilling in the field of optimisation, an opportunity fitting with the PhD programme and with the research project. For IBM, the internship was an opportunity to attract an early-stage researcher with breadth and depth, and to gain an experience-based insight into her abilities. This engagement indicates how such students, having completed a significant amount of Engineering and Business research and Innovation and Entrepreneurship training are attractive as researchers and as potential future employees.

2 DISCUSSION

Doctoral education continues to develop, in line with advances in undergraduate education, research infrastructure, research opportunities and societal expectations. The corresponding changes in curriculum design, while potentially beneficial and well regarded by students and industry, nonetheless challenge the established approach to education and to supervision. Here, the challenge may be framed in terms of a trade-off – of depth and disciplinary purity against breadth and inter-disciplinarity. Correspondingly, while recognising the need for change in Engineering Education at PhD level, many previous investigators have highlighted that a risk exists in expanding the scope of a PhD to include a number of complimentary areas. i.e. students may gain a breadth of knowledge at the expense of the technical depth they would have otherwise attained [3]. Furthermore, arguments have also been put forward that the potential ‘dilution’ of the traditional PhD may reduce the quality and scope of the research output. Further, there is also considerable (and understandable) resistance to modifying the current PhD curriculum model as research funding is critical to sustaining and growing Engineering PhD programs, and a reduction in research output may hinder the success of academics in attaining such funds in future.

An alternative framing of the challenge is to see it in terms of an extension of the performance frontier, and not a trade-off. From this perspective, there is value in developing competence in both Engineering and in Business, rather than either-or. The Eng-Bus PhD proposed here is located within this alternative framing and is visualised as enabling the T-Shaped researcher, where both the web and the flange contain research and training. It cannot be argued that the breadth gained in business is not at the expense of a certain amount of the depth in Engineering, as the time placed on this element of their PhD projects could have been sent on Engineering work in the traditional model. However, it is the authors’ view that the value of the breadth gained outweighs this small loss in depth, so enabling an expansion of the performance frontier. The prospect for this kind of researcher has implications for the student selection and experience. As a key aim of the PhD research is to produce a number of publications covering each element of the work, including the business research. Further, the supervision arrangements are consistent with the T-shape, with implications for supervisor selection and interaction. Finally, the development of the T-shaped researcher requires that within the institution there are educational opportunities, such as in the Innovation Academy, which support and recognise interaction among doctoral researchers from different disciplines and application of doctoral research in practice.

3 CONCLUSIONS

Educating Engineering PhDs to be innovative and entrepreneurial is a timely challenge for educators, for students and for industry. More particularly, an opportunity now exists within Irish higher education for Trinity, as Ireland’s leading University, to take the lead in developing an integrated approach to innovation and entrepreneurship in Engineering Education. This approach has the potential to serve social and economic objectives including environmental protection, economic development and job creation. This paper presents a description and reflection on an educational intervention designed to make this aspiration a reality. The vast majority of traditionally-educated Engineering PhD students will progress to a career in industry where ‘non-technical’ skills are of considerable importance. This paper demonstrates how Engineering PhD Curriculum Development and Supervision models may be modified to prepare the students be innovative and entrepreneurial in this context. The resulting PhD programme produces Engineering Doctorates with both a deep understanding of a specialist area of Engineering but also with a broad knowledge of how their practical Engineering outputs may contribute/fit in practice. Innovation and Entrepreneurship training together with elements of independent business research are key enablers in this process.

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