Exploiting the Thesis Research: Educating Engineering PhD Students to Think and to Act Entrepreneurially

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INTRODUCTION

In preparing their thesis, doctoral researchers are challenged to address significant issues with the potential to contribute to knowledge. Increasingly, there is an expectation of societal relevance in the research topic. In essence a research-based response to the grand challenges facing society today is needed. In addition, it is widely accepted that the academic career path is an option only available to the minority of PhD graduates in Engineering today [1]. The vast majority will progress to a career in industry where 'non-technical' skills 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 is 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 [4].

Innovation and entrepreneurship are key transferable skills which are considered vital to preparing Engineering PhD students for careers in industry [4]. 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 [5]. 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 [6]. 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 [7]. In response to this, the resulting thesis may form the basis for an innovative and entrepreneurial response to an issue. To realise this potential, doctoral education needs to enable collaboration with other disciplines and with practitioners, and to encourage thinking and acting innovatively and entrepreneurially.

This paper outlines a longitudinal case study of Engineering PhD students who have engaged in the Graduate Certificate in Innovation and Entrepreneurship programme which is offered to all doctoral students, including Engineering, at Trinity College Dublin as part of structured PhD Programmes. The paper is based on student interviews and programme documentation. The integration with the

Engineering curriculum is outlined, including, student progression and supervision. The paper also reflects on the benefits in terms of graduate attributes and employability.

1 DOCTORATENESS

1.1 The Traditional Components of Doctorateness

High quality doctoral research and a coherent thesis is the basis for the original contribution to knowledge which is key to the award of a PhD. Trafford & Leshem [8] defined 'doctorateness' in terms of a set of components comprising:

- high levels of competence in research skills
  - appropriate choices on methodology, explicit research design, 'correct' data collection
- deep discipline knowledge
  - a clear contribution to knowledge; a stated gap in knowledge; an explicit research question; a cogent conceptual framework
- competence in presentation of aural and written argument
  - clear/precise presentation; full engagement with theory; cogent argument, throughout; research question answered; and conceptual conclusions offered.

'Doctorateness' is achieved when candidates can demonstrate synergy across these key components identified in the conceptual map in Figure 1. Until candidates recognise the theoretical and practical significance of doctorateness their ability to produce high quality research and coherent theses will be limited.

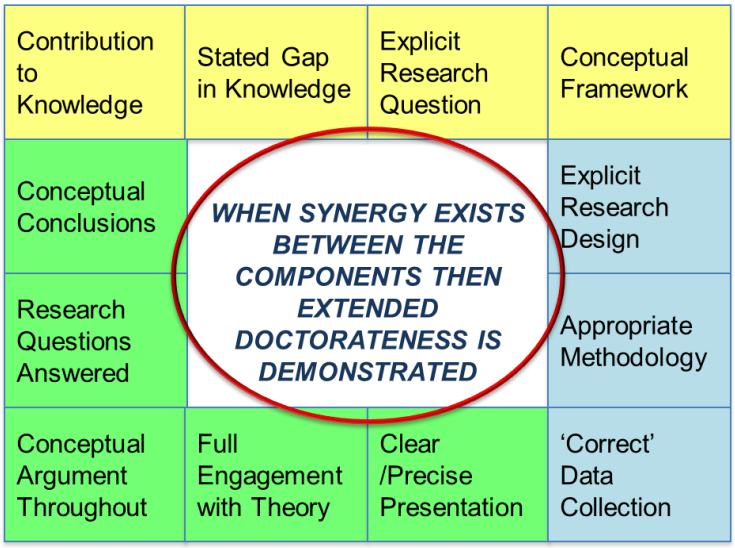

Figure 1. Components of extended doctorateness (adapted from [9]).

1.2 Extended Doctorateness

Graham-Cagney and Coughlan [9] explored the boundaries of the traditional components of doctorateness and proposed a modified concept of extended doctorateness. Here, in addition to the traditional components, students ambitious to explore and to contribute to knowledge and to practice need to integrate cross-disciplinary working, pitching research, reconciling difference, linking to practice, creative thinking and confidence in application of additional components. As illustrated in Figure 1, demonstrating extended 'doctorateness' comes from integrating not just high levels of competence in research and deep discipline knowledge, but also competence in linkage, application, and presentation of the argument. This extension is consistent with the needs of doctoral research

which crosses disciplinary boundaries and which aims to contribute also to practice. The corresponding change “thinking and talking” is illustrated in Figure 2.

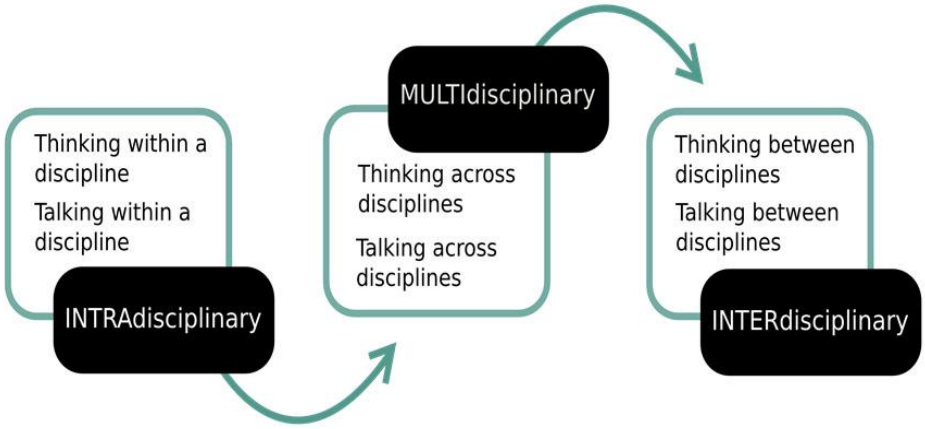

Figure. 2. Thinking and talking towards a different perception of Doctorateness (adapted from [10]).

1.3 Engineering Curriculum

All PhD programmes in the School of Engineering at Trinity College Dublin in Ireland are structured, and research students are required to undertake taught modules to support their research and postgraduate education as part of these programmes. PhD students are required to complete a minimum of 10 to 30 ECTS of taught modules, depending on which PhD programme they are enrolled on in the School. The modules selected by student are defined by the School of Engineering as enhancing the candidate's breadth and depth in their area, strengthening their research and research-related skills, or providing other expertise that may enhance their potential career opportunities. These modules may be:

- Discipline specific, i.e. related to the student’s field of research
- Generic engineering, i.e. supporting a wide range of engineering research
- Broad curriculum, i.e. intended to expand a student’s learning experience

As such the School recognises the need to enhance the career opportunities of PhD students, and that this may be provided by broad curriculum type learning, outside the scope of material taught in traditional engineering disciplines.

2 INNOVATION ACADEMY

2.1 Developing the Graduate Certificate Course

In an initiative to enable doctoral students to recognise the theoretical and practical significance of their thesis research Trinity College Dublin developed the Graduate Certificate in Innovation and Entrepreneurship course as part of a structured PhD Programme. The course is offered to all doctoral students, including Engineering. The course locates entrepreneurship and creative thinking in the context of the thesis and challenges students to explore and to exploit innovative opportunities for commercial and/or social application and benefit in the thesis. This course is transforming the doctoral education experience of students by establishing innovation alongside research and education as an integral element of their PhD. The output is a new breed of graduate, expert in their discipline, but confident in innovation and entrepreneurship.

The development of the course began in 2010 and has continued to the present day. The initial steps focused on the development of the concept, the package and the process. Here, the concept was to reflect an understanding of the nature, use and value of the programme for different users. These

users included students, supervisors, funding agencies and the University. The package included the programme (and associated components) providing the benefits defined in the concept. Finally, the process to be developed included the way in which the programme (and associated components) was to be created and delivered. Taking these initial steps challenged those involved to be design thinkers [11] with empathy, integrative thinking, optimism, experimentalism and collaboration.

2.1 What has the course involved?

The Graduate Certificate in Innovation and Entrepreneurship was the first programme to be developed and delivered by the Innovation Academy. The structure of the programme comprises core and specialised modules which may be taken over one to four years. The participating PhD students are drawn from across all disciplines. Students are anchored in the disciplines, where they will pursue original research relevant to key strategic objectives. Training and education is delivered within a vibrant multidisciplinary environment, facilitating new ways of thinking and helping to uncover commercial opportunities in doctoral research. Figure 3 illustrates the curriculum design, including the modules, teaching-learning strategies and learning outcomes. These learning outcomes link directly to enabling the transition from traditional doctorateness to an extended doctorateness.

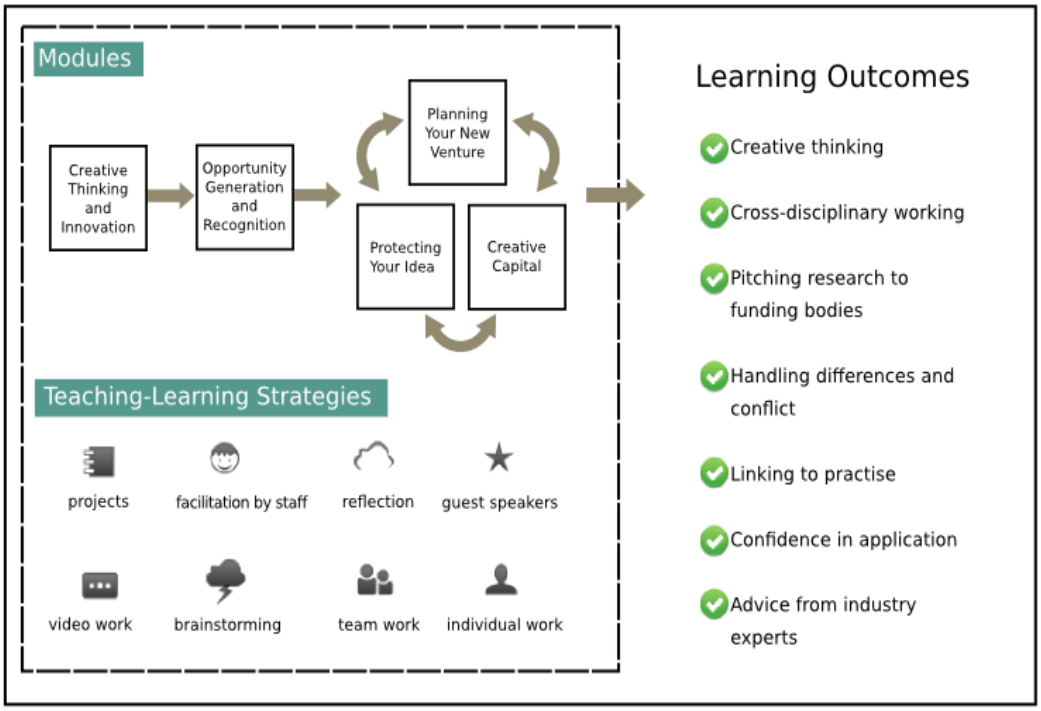

Figure. 3. Curriculum Design. (adapted from [9]).

The course links between research, education and action based upon a view of innovation in its broadest sense of exploiting new ideas in a competitive world; it is not restricted to science, engineering, technology or business, but encompasses creativity, leadership, cultural and policy innovation of arts and humanities. A key course objective is to enable the student to apply critical insights from participation in the course to their PhD thesis through exposure to working across disciplinary boundaries with others, all of whom are outside of their discipline-based 'comfort zones'. Throughout the course, students are exposed to the experiences of researchers who have gone before them and who have been innovative and entrepreneurial in exploiting the potential of their research. The modules are designed to address the main issues and problems that entrepreneurs and creative thinkers face in recognising, developing and assessing innovative opportunities for commercial and/or social benefit. The modules are structured in such a way as to encourage action, participation, discussion, analysis and reflection. As a postgraduate course offered to PhD students, the students are expected to be self-directed, proactive and enterprising.

3 LONGITUNDINAL CASE STUDY

3.1 Subjects

Over the past three years, over 300 students have participated in the Graduate Certificate in Innovation and Entrepreneurship. This number included 31 Engineering students at differing stages of their programmes of studies. Table 1 summarises the pattern of participation of these students in the programme. Consistent with the ambition of the University, participation is becoming an integral part of the Engineering curriculum.

Start Year on Programme	*2010-2011*	*2011-2012*	*2012-2013*	*2013-2014*
Number of Students	7	14	8	2 (provisional)

Table 1. Distribution of Engineering Students participating in the Graduate Certificate in Innovation and Entrepreneurship by Start Year on Programme

Table 2 summarises the key characteristics of these Engineering students. The participation across disciplines within engineering is concentrated on Bio-medical, Civil and Mechanical & Manufacturing Engineering. The drivers for participation in these cases include research funding, opportunities for application and commercialisation of research, individual supervisors, and the existing Engineering PhD curriculum.

Engineering Discipline	**Number of Students**	**Number of Unique Supervisors**	**Student Gender Balance**	
			Male	**Female**
Acoustics	1	1	1	0
Bio-medical	10	9	8	2
Civil	7	6	3	4
Electronic	2	2	2	0
Environmental	2	2	1	1
Mechanical and Manufacturing	9	8	7	2
6 DISCIPLINES	**31 students**	**28 discrete supervisors**	**22 male**	**9 female**

Table 2. Engineering Students participating in the Graduate Certificate in Innovation and Entrepreneurship

3.2 Feedback & Reflection

The Creative Thinking and Innovation module is one of the two core modules offered in the Graduate Certificate in Innovation and Entrepreneurship. Running over three weeks, it is central to the formation

of a basis for extended doctorateness. As part of their reflections at the end of this module, one of the Engineering students wrote:

> *'The three week module on Creative Thinking and Innovation was very beneficial and definitely a worthwhile process for me. It was a great opportunity to work in a team environment again and learn from people with different ranges of work experience and academic background, particularly as PhD work can be very isolating and the level of interaction with others can be limited.'*

The Opportunity Generation and Recognition module is the second of the two core modules. Here, the students prepare a short video based upon their thesis research topic. The module introduces the students to the rationale and process of capturing complex research findings using video including organising empirical data, visually representing theoretical concepts and communicating PhD research to non-expert groups, the wider academic community and potential industry partners [12]. At the end of the module, one of the Engineering students wrote:

> *'This has been another long and very busy week, but again ultimately very rewarding. I was again taken completely out of my comfort zone and it was great! I have learned a lot about film making-focus, lighting etc as well as editing on iMovies – adding music, splitting audio, transitions etc… I have got incredible practical film-making and editing experience that will be of great use to me in the future. I have made a video describing my research that will also be very useful for presentations and pitches. The guest speakers were all inspiring and gave useful tips and information on how to turn research into a commercial or social venture. It was great to spend another week with the other PhD students from module 1 (and also to meet some of the students from the previous year), everyone got on really well and the group work was good fun.'*

Reflecting on his thesis research during the course, one Engineering student noted:

> *'It is not enough just take a 'blank page' approach to design, where students design products and technologies from entirely from scratch…Engineers will likely work on a project that has already begun and they need to be able to respond to what has happened before they began to participate, understand it and then move from that point, in a collaborative way, to advance it.*

As a set, these comments indicate an impact on the students' perceptions of their own research, the value of interaction with others in a team, and the appreciation of, what are becoming, generic communication skills. Positioning one's research focus, knowing how and with whom to interact, and pitching are essential elements in the exploration and exploitation of entrepreneurial opportunities.

4 DISCUSSION

4.1 Integration with Engineering Curriculum

The compulsory taught modules to be completed by students as part of their structured PhD are required to be selected in consultation with their supervisor, taking into account their individual circumstances and requirements in light of their prior qualifications and their research project. As such the degree to which a student's supervisor is open to the idea of entrepreneurship education and the Innovation Academy in Trinity influences student's potential engagement in the Graduate Certificate in Innovation and Entrepreneurship to a certain degree. Placing the current level of engagement of Engineering PhD students with the Innovation Academy to date into context, of the total 191 students enrolled in the School in 2011/12 16% have participated in the course. This figure has been growing steadily since the inception of the Innovation Academy 3 years ago.

No explicit mention of innovation or entrepreneurship skills are currently outlined in the curriculum of PhD students, however students are advised of a number of potential courses within and outside of the School from which to select suitable modules, including the Innovation Academy. In addition students enrolled on a specific PhD programme, the Graduate Education Programme in Engineering, are specifically required to complete 30 ECTS from modules offered by the Innovation Academy [13]. As such the growth in the numbers of Engineering students attending innovation and entrepreneurship education as highlighted above can be seen to be somewhat related to the specification of this as a required element of the curriculum for some students and a suggested element for others.

4.2 Student Progression & Supervision

In Trinity, many approaches to supervision are evident. They range from the team-based to the traditional master-apprentice models. In all cases, supervision is provided from within a School and there is a concern to maintain a strong disciplinary focus and identity. Educating engineers to be innovative and entrepreneurial challenges this model. While the student, ultimately, must defend a thesis with a strong disciplinary identity, the innovation and entrepreneurship focus brings in the opportunity for multi-disciplinary research and, even, application of that research in practice. McNabola and Coughlan (2013) outlined a model of supervision, the T-shaped approach, which addresses this challenge. The application of this model is evident in the supervision of a number of the engineering students discussed earlier. While many of the other students have experienced different models of supervision, in all cases their participation in the Innovation Academy has brought them into contact with different students and faculty from disciplines and challenged them to look at their research from those alternate perspectives. Effectively, in terms of doctoral student formation, the supervision of their development has expanded beyond the School boundaries and beyond the traditional and, even, T-shaped models. The implications for supervisors and for graduate student administration are not trivial. Supervisors' expectations have to be accommodated in the development of the programme of study for “their” students, while the supervisors have to be open to ceding an element of control to others outside of their discipline. For the administration, there is the issue of maintaining visibility of the responsible faculty for student development and progression and for allocating resources appropriately.

4.3 Graduate attributes and Employability

The opportunities for employment of newly qualified doctoral students continue to change. Gone is the certainty of a seamless progression into a career in academia. Instead many graduates go directly to industry or take up postdoctoral positions with the hope of exploiting their thesis research and enhancing their employability. These options may require the graduate to interact with others in order to exploit and apply the findings of their thesis research. It is in this context that educating engineering PhD students to think and to act entrepreneurially finds relevance.

5 SUMMARY

This paper outlines the basis for educating engineering students to think and act entrepreneurially currently on offer to all PhD students in Trinity. The benefits of this educational intervention have been highlighted in terms of improvements in student career opportunities and attainment of extended doctorateness. Students engaged in the programme have provided positive feedback on their participation in the Graduate Certificate in Innovation and Entrepreneurship, demonstrating an impact on perceptions of their own research, an appreciation of the value of interaction with others, and an appreciation of the generic communication skills developed.

For Trinity the further development of this educational intervention is of strategic importance. The University has recently launched a strategy for innovation and entrepreneurship which lays out the ambition of the University in this area and key steps to achieve that ambition. The intervention is coming to the notice of other Universities from across the world. During the current academic year Trinity has hosted groups for extended visits during which time they have taken the opportunity to understand the approach taken and to reflect on the application of that approach in their own contexts. These visits have benefited Trinity also, in providing an opportunity to articulate the approach and to hold it up for constructive questioning.

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