The Engineering Doctorate (EngD)

Developing Leaders for Tomorrow with Industry

Professor Patrick Godfrey

University of Bristol

Patrick.Godfrey@bristol.ac.uk

Abstract

The development of the Engineering Doctorate (EngD) in the UK is traced. A differentiating purpose is the creation of future leaders with industry as compared with PhD's which although valued in industry, have the originating purpose of creating future leaders for academia. How EngD's purpose is met is summarised. Value is added in 4 ways such that the whole is more than the sum of its parts. The value for industry is in the research and development it generates. Government has an expanded resource of industrial leaders with professional competence for innovative interdisciplinary research and development. The University gains publishable contributions to knowledge that are the hall mark of a Doctorate and a world class Engineering Research Centre. The value for the individual is in career development potential and an opportunity to make a difference. The success of the EngD development programme over the past 20 years is a consequence of the EPSRC funding of Industrial Doctorate Centres (IDCs) which are true collaborations with industry. By focussing on need and purpose rather than prescription, the IDCs provide a flexibility that supports innovation and creativity. Because it is founded on industrial experience, the whole process is well aligned to the development of professional engineering competency. The need to develop and protect the brand of an EngD as well as the network of Research Engineers and Alumni has led to the establishment of an Association of EngDs (AEngD). It is also noted that there is a proposal to create a European Engineering Doctorate that should reflect the same kind of purpose, quality standards, flexibility and diversity. It is intended that it will respond to the particular needs of the local industries and educational contexts across Europe.

Having a doctorate

The origins of universities and doctoral qualifications are in the mediaeval craft guilds and the church. They were both associated with building the great cathedrals; where the apprentice became qualified by the submission of a master piece accredited by the master craftsmen in the guild. "*The PhD acquired its modern status as the highest research degree in the early nineteenth century in Germany. The PhD candidate followed a form of 'apprenticeship', and was normally awarded the degree in middle age. In 1861, Yale University began awarding the degree, abbreviated as Dr. Phil., to younger candidates who had completed a prescribed course of graduate study and successfully defended a dissertation containing original research in science or in the humanities."*[1]

Since 1990 in UK , the doctoral qualification has diversified leading to differently structured degrees to accommodate the needs of different professions eg Doctor of Education, Doctor of Medicine, Doctor of Social Science, etc alongside the overwhelming majority of Doctors of Philosophy or PhDs.

However the Quality Assurance Agency for Higher Education (QAA) has published a guide to Doctoral degree characteristics[1] which provides a summary for the UK, highlighting similarities and differences between doctoral degrees. It includes a set of Doctoral descriptors which are a requirement for all doctoral qualifications. There are

differences in detail for England, Scotland and Wales but they all require that Doctoral degrees be awarded to students who have demonstrated:

- *the creation and interpretation of new knowledge, through original research or other advanced scholarship, of a quality to satisfy peer review, extend the forefront of the discipline, and merit publication*
- *a systematic acquisition and understanding of a substantial body of knowledge which is at the forefront of an academic discipline or area of professional practice*
- *the general ability to conceptualise, design and implement a project for the generation of new knowledge, applications or understanding at the forefront of the discipline, and to adjust the project design in the light of unforeseen problems*
- *a detailed understanding of applicable techniques for research and advanced academic enquiry.*

The UK doctorate in all its forms has been confirmed as being in alignment with European-wide guidance, in particular, with the Framework for Qualifications of the European Higher Education Area (EHEA), through a verification process led by QAA in 2008.[1] The EngD is a third-cycle qualification in the Bologna process.

Why was the EngD needed?

The basis for the EngD in UK was established by the Parnaby report (1990[2]) which concluded that an Engineering Doctorate should be "*distinct from, and complementary to, the traditional existing PhD, which has been criticised for its lack of industrial relevance.* It recognised that there *is a place in industry for PhDs but, companies which research, develop, design and manufacture plant equipment and systems" .... "as well as IT based firms" .....* viewed "*the PhD is both too narrow and academic for the industry's needs and that its standard is declining*"! This last observation is significant because it is recognised that there is a clear need for enhanced quality compared with the PhD as it was then.

What was needed?

The Report recommended to the then SERC (Science and Engineering Research Council) that:
"A pilot doctoral programme, encompassing a broader range of training be established alongside the traditional PhD. Whilst the framework of this programme should be flexible enough to respond to the needs of industry and the doctoral candidates it needs to contain the following components:

a) A significant, challenging and original engineering problem or set of problems undertaken as a partnership between industry and academia. This should be designed to give the candidate experience in team work, engineering project management (including financial aspects and working within prescribed time scales) in addition to in depth knowledge of an engineering problem.
b) Taught coursework (of high quality and assessable) to complement and enhance the experience of the individual in both technical and non-technical areas."

How has the EngD developed?

In response to the Parnaby report (1990[2]) SERC and its successor EPSRC have sponsored expanding programmes of what are now called Industrial Doctorate Centres (IDCs) (that generally award EngDs) and since 2009 Doctorate Training Centres (DTC) (that generally award PhDs). They are collectively referred to as Centres for Doctoral Training (CDTs). This has stimulated the development of a thriving programme of research and teaching, as well as the creation of collaborative research networks, integrating industrial and academic needs in areas at the frontier of development. There are currently 27 IDCs sponsored by EPSRC (see Table 1) and a similar number of DTCs. In addition, EPSRC award doctoral training grants (DTA) to universities based on research grant income. They also make Industrial Case Awards where businesses take the lead in arranging projects with an academic partner of their choice as a well as Case Awards to encourage industrial collaboration in PhDs.

All the IDCs are interdisciplinary Centres where the theme identifies the mix of disciplines required. Many are partnerships between universities and have a diversity of Industrial Partners and more fundamental research programmes. More than 270 companies are currently sponsoring about 1000 Active REs with some companies sponsoring multiple EngDs in several Centres.

Each centre offers a combination of Masters level, business, and technical teaching as well as the programme of doctoral research in industry, for industry. It is this industrial context and motivation that differentiates the EngD from other Doctorates. In the process students, who are referred to as Research Engineers (REs) (because 'student' can be a pejorative term in Industry,) are presented with some major challenges to their personal leadership skills. This is particularly important where the RE is effectively leading his or her contribution to an innovative program of work. The RE has to align 3 different sets of stakeholder needs: The Industry sponsor, the University and his or her own career development.

The diversity of industrial contexts and motivations for the investment in the EngD dictates that there can be no fixed prescription for the research. Instead the RE has to become a programme manager successfully delivering outcomes required by all three stakeholders. This is an essential element of the leadership and professional engineering development that is required.

Students can be funded by stipend or as an employee. Stipends can be funded by EPSRC or from Industry either through company contribution to IDC for top up funding or through a subscription to the Centre for the whole cost. Most EngDs are formulated as a broadly defined project that is often a part of an industrial development strategy. Even if the RE is funded by stipend, the industrial partner will treat the RE as an employee, by agreement. Generally the project will be broken down into tasks to meet short term goals and integrate with other corporate activities. Some large companies have a progression of REs addressing different facets of a major programme. Some will use the RE as researcher or designer in a development team.

Table 1	**EPSRC Industrial Doctorate Centres**[3]
Appointed in 2009	**Theme**
University of York	Large-Scale Complex IT Systems
University College London	Bioprocessing Engineering Leadership
University of Southampton	Transport and the Environment
University of Bath	Digital Media, Special Effects and Animation
University of Nottingham	Efficient Power from Fossil Energy and Carbon Capture Technologies (EPFECCT)
University of Bristol	Systems
University of Surrey	Micro- and NanoMaterials and Technologies
University College London	Urban Sustainability and Resilience
Cranfield University	Skills, Technology, Research, and Management (STREAM) for the UK Water Sector
University College London	Virtual Environments, Imaging and Visualisation
The University of Manchester	Nuclear Engineering
Newcastle University	Biopharmaceutical Process Development
University of Reading	Technologies for Sustainable Built Environments
University of Birmingham	Formulation Engineering
Heriot-Watt University	Optics and Photonics Technologies
University of Surrey	Sustainability for Engineering and Energy Systems
University College London	Molecular Modelling & Materials Science
University of Oxford	Systems Approaches to Biomedical Science
Loughborough University	Innovative and Collaborative Construction Engineering
Appointed since 2009	
University of Birmingham	Doctoral Training Partnership (DTP) in Structural Metallic Systems for Gas Turbine Applications.
Imperial College London	Non-Destructive Evaluation
University of Strathclyde	Industrial Doctorate Centre in Advanced Forming and Manufacture
Swansea University	MATTER- Manufacturing Advances Through Training Engineering Researchers
University of Sheffield	Machining Science
University of Nottingham	Manufacturing Technology Centre (MTC)
University of Warwick	High Value, Low Environmental Impact Manufacturing
University of Edinburgh	Industrial Doctoral Centre for Offshore Renewable Energy (IDCORE)

Industry needs

Generally industry is seeking industrially relevant research and development and high quality engineering leaders of change and innovation from their investment in the programme.

Most Industrial Doctorate Centres have some form of Strategic Advisory Board (SAB) to inform the development of the programme. The industrial members are usually at Chief Technical Officer level and meet about twice a year. The SAB at the Universities of Bristol and Bath, has emphasised the importance of leadership and professional development as well as their detailed research work. As an exemplar, a Director of a large civil engineering consultancy has reported: "*As a leading UK-based engineering design consultancy (7000 staff), with substantial interests in the areas of buildings and transport, water, maritime and utilities infrastructure.... we are increasingly of the view that the complex, real-world problems and issues that confront us cannot be properly addressed using mono-discipline approaches alone.*

Our Research Engineers are already contributing strongly to our strategic thinking, and are in close and frequent communication with Group Board members. They are already quite literally changing the way the company thinks." Table 3 provides an indication of industry needs and satisfaction levels from a limited survey of 11 industrial sponsors and presented as part of the recent EPSRC review.

Table 3 Survey of 11 Industrial sponsors (2011)

Survey question	**Satisfaction (* / 5)**
Stimulating innovation through collaborative research	4.5
Recruiting and retaining talented people	4.3
Developing technical, business and personal leadership skills in staff	3.6
Is the EngD good value for money?	4.1

University/Government Needs

The Industrial Doctorate Centre's grants are generally awarded to research led Universities or partnerships of Universities that have already established a track record and good relationships with industry, in the theme. Having critical mass is an important attribute of being a centre. The requirement for the doctorate is academically rigorous research that will satisfy: the examiners; the University's own quality assurance process and contribute to the University and academic supervisors' reputations. Research led universities establish a synergy between their research and teaching programmes that adds to the impact from the research and to the attraction of the teaching.

Government's requirement may be inferred from the Funding Council requirement which is summarised as follows: *to contribute to the economic competitiveness of the UK and the quality of life of its people*[4]. EPSRC select and monitor each Centre based on objectives proffered on application for funding. In this way the research and the doctoral training are measured in accordance with current EPSRC policy. EPSRC also provides regularly updated IDC Good Practice Guidance[3] Each IDC is subject to regular performance review (every 4 - 5 years for funding application with a midterm review), the latest performance review having been completed recently. The Guidance emphasises the need for academic quality: *The test of intellectual contribution for the award of an Engineering Doctorate (EngD) shall be at least equivalent of that for the PhD degree (i.e. a distinct 'contribution to knowledge' or similar). Where the research work for the EngD consists of a series of linked projects these must be brought together by an overarching document that establishes the overall purpose and synergistic links in the work that lead to the contribution(s) to knowledge claimed. (N.B. a series of essentially distinct projects would be unlikely to allow a contribution to knowledge to be demonstrated.)*[3]

The RE's Needs

Career development and an opportunity to make a difference, seem to be two important drivers for the RE. The RE can be at the start of an engineering career or in a mid career personal development process. The RE must have the equivalent of a UK 2.1 or better undergraduate degree in engineering or in some cases science/mathematics. Most, but

not all, will have an accredited Bologna second cycle qualification since that is the usual requirement for qualification as a Chartered Engineer in the UK. Since the challenge of the EngD is success in a multicultural, multi-discipline environment and ability to live with some ambiguity and uncertainty; communication and personal leadership skills are challenged. The RE needs to be a self starter from the outset. This can differentiate EngD candidates from those seeking PhDs. One academic supervisor described the REs as knowing WHY they were doing the research, where as in his experience that was not necessarily true of PhD researchers. Industrial Doctorate Centres are reporting a large surplus of 'serious' candidates for the stipend positions: 5-10 applicants per place for established Centres.

Most of the mid career REs are employees, who are either being prepared for leadership positions associated with the employers' motivating theme or are in organisations where having a doctorate improves promotional opportunities. These mid career REs require a stronger business case because the corporate costs are higher. However this tends to mean that the company and RE are even more highly motivated. Often the organisation will fund technicians to work under the direction of the RE and equipment that enables or accelerates the research. Some stipend REs have been encouraged by early payback on their work to justify similar investment. This commercial orientation is entirely consistent with the original aims of the Parnaby Report and the commercial and technical leadership requirements for professional engineers. Time to market is critical for industry and impact.

The benefit to an RE is illustrated as follows.*: "I benefit immensely from academic knowledge that I apply directly to my everyday work experience. It is unique in that I am solving a real industry problem that hasn't been solved before, and the results could be applied across the industry. If you are full time employed and not an RE, it is difficult to see and to solve problems in the organisation, but as an RE, you see the organisation with a third eye from an academic point of view, and you are better placed to see and solve problems (only if the managers can listen!)"* [5]

Teaching and Networking

The EngD is normally four years duration. The REs are expected to spend around 75% of their time working directly with the collaborating company on project work and 25% on taught courses. These courses are generally at Bologna second cycle level and designed to support the programme of research being undertaken. Some Centres choose to provide a major proportion of this teaching in the first year whereas others prefer a more reflective approach, in parallel with the research. In this latter case, formative and summative assignments can be designed that contribute to the industrial goals and the ultimate thesis.

The teaching will not only cover the Centre technical theme (Table 2) but also provides teaching in research methodology, business and transferable skills including such areas as communication skills and ethics. Furthermore "*EPSRC expects IDCs to be exemplars for the student training experience, specifically for developing and*

enhancing individuals' creativity. Centres should provide students with an inspirational environment to enable their creativity to flourish"[3].

As with most educational experience, peer to peer learning is a very important component. Whilst work in industry contributes to the acquisition of professional experience, There is a risk that it can isolate REs from academic peer to peer learning Each centre works to develop a cohort and network centric ethos enabling self organised groups to meet physically and virtually as well as organising seminar and conferences for industry and academic interaction.

It is been noted that the lifecycle of many industrial tasks can be much shorter than that for the 4 year timeframe of an EngD. It is also not uncommon for the industrial goals to be met without the creation of formal contributions to knowledge, feedback of learning or academic rigour. REs are encouraged to publish or produce publishable papers on their work as they proceed. Intellectual Property considerations may inhibit open publication and external peer review however these problems can often be overcome by the RE through skilled stakeholder management. Internal peer review within a company can provide an important communication channel and grounding for qualitative research. The papers and assignments should be an evidential basis for the abstraction of the thesis and are often included as a CD in the thesis. They make the ultimate task of writing up more manageable. The existence of published papers provides the examiners with a practical demonstration that the work is of publishable quality.

Being a Chartered Engineer

The opportunity exists to enable fast track development for professional engineering leaders. An important part of this is qualification as a Chartered Engineer[6]. This professional engineering qualification, which recognises technical, personal and professional competence, stemmed from the same origins in the craft guilds as the Doctorate and was developed in the UK with the formation of Professional Engineering Institutions, initially the Institution of Civil Engineers in 1818. It was at this point that Civil engineers were differentiated from Military Engineers. There followed a fragmentation of the profession as different branches of engineering developed during the Industrial Revolution and since. In 1982 in UK, the Engineering Council was set up to establish uniform standards of engineering qualification in one national body[7]. Currently there are 36 institutions licensed by the Engineering Council to accredit degrees and company training schemes, and to assess the competence of individuals who are seeking professional engineering status, according to Engineering Council standards[7].

In a document known as UK SPEC[8], the Engineering Council characterises Chartered Engineers "*by their ability to develop appropriate solutions to engineering problems, using* ***new or existing technologies, through innovation, creativity and change.*** *They might develop and apply new technologies, promote advanced designs and design methods, introduce new and more efficient production techniques, marketing and construction concepts, or pioneer new engineering services and management methods.* ***Chartered Engineers are variously engaged in technical and commercial leadership and possess effective interpersonal skills."*** UK-SPEC is supported by guidance material covering topics such as ethics, risk and sustainability[9]. It is interesting to note that several of the points emphasised in this guidance, for example the importance of

engineers applying professional and responsible judgement, and taking a leadership role, are central to the development of REs during the EngD. .

The Engineering Council is working with the licensed professional engineering institutions to produce a statement about the relationship between the EngD and achieving qualification as a Chartered Engineer. The recent publication of learning outcomes specifically for second cycle degrees (other than the integrated MEng, which were published some years ago), paves the way for work on how the EngD, which is at a higher level in the qualifications framework, might be accredited as an academic award. Initial work suggests that there might also be opportunities to consider the EngD as an integrated education and professional development (training) package. The Registrations Standards Committee of the Engineering Council has recently advised its Licensed Members that: *"Subject to further work being undertaken on the process for accreditation of the EngD, for the purposes of CEng registration, an accredited bachelors degree with honours in engineering or technology plus an accredited EngD will provide the full exemplifying award.*

In the meantime, in line with the statement in UK-SPEC, institutions should consider the EngD as 'appropriate further learning to masters level', and consider an EngD holder as being in a broadly comparable position to someone who has completed an accredited Initial Professional Development (IPD) scheme."

Association of Engineering Doctorates (AEngD)

Although there are a few thousand alumni and REs, it takes time and effort to create the industrial and public understanding of what an EngD is and to protect it from less scrupulous institutions that seek to dumb down the quality standards. There is also a need to develop the network of centres, REs and alumni that will both demonstrate the value added and be the future 'master craftsmen' who communicate and protect the quality of the qualification. The EngD has 'employment' value analogous to the MBA. We have already observed industrial partners who have transferred REs from stipend to employed status half way through their programme to secure their services over a longer term. For these reasons the Industrial Doctorate Centres have formed an Association of Engineering Doctorates (AEngD) which is a ***forum*** *for EPSRC-funded* ***Industrial Doctorate Centres*** *in the UK. It was established in 2010 to:*

- *support EngD brand-building, including acceptance and recognition of Engineering Doctorate (EngD) degrees within host institutions and industry*
- *promote excellence and maintain quality of EngD degrees*
- *develop wider and more strategic industrial research collaboration*
- *identify and promote the benefits and impacts from EngD research*
- *recruit sufficient and suitable top quality projects*
- *attract and recruit high calibre Research Engineers (REs)*
- *encourage strong academic engagement*
- *promote and develop taught programmes tailored to REs and industry needs*
- *be a social network for Industrial Partners, REs and Alumni*
- *feed back into the host institutions' research base*

European Engineering Doctorate

In several European countries (e.g. UK, the Netherlands, Sweden, France) Bologna third cycle industrially driven engineering programmes already exist. Although these programmes are all organised in their own specific way, they share a similar objective, namely: "*to deliver top-level engineers who have made a contribution through original engineering research in a business context that extends the frontier of knowledge on a particular industrial sector, multidisciplinary theme or technological discipline, who have developed competencies for a broad range of engineering roles in industry or society, and who are able to enhance collaboration between academia and companies*"[10]. It is being proposed that a European Engineering Doctorate be established that will have international recognition and a common accreditation process.

Conclusions

The EngD originated from recognition that although valuable, the traditional PhD was not designed to develop the innovative technical and business leadership skills needed by industry.

The EngD has been developed over the past 20 years in UK through the creation by EPSRC of what are now known as Industrial Doctorate Centres which become centres of research excellence and inter-industry/academic networks in themselves.

The EngD is a Bologna third cycle doctoral qualification, that is focused on creating engineering leaders who are able to combine the rigour required to deliver a doctoral level thesis, which is at least as intellectually demanding as is required for a PhD, with the technical and business skills and leadership to innovate in industry. In the Process the RE becomes a catalyst for collaboration: "*One of the best ways of achieving a good connection between two research groups, be they two academic, or an academic and an industrial one – is to have a person who is located in both, and these students fulfil that role.*" An Industrial Supervisor.

The EngD qualification is evidently attractive:

- to high quality engineering first and second cycle graduates.
- to industry who through fees, supervision and support, invest as much as the funding agency and University in the process.
- as a mid career development process for valued employees.
- to the Government of UK who need to regenerate our industrial economy.
- internationally as well as nationally

The development of EngD competence development, is founded on industrial experience, and so is consistent with the route to chartered status in UK via a Company Training Scheme. The alignment of the two processes is recognised. Action is in hand to ensure that mentors have knowledge about professional standards, so that a minimum of time will be taken in career development of engineering innovators who are leaders for tomorrow. There is no substitute for the experience of innovation and leadership to develop innovators and leaders with industry.

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