INNOVATIVE DOCTORAL TRAINING AT UNIVERSITIES OF SCIENCE AND TECHNOLOGY

DISCUSSION PAPER

CESAER
conference of european schools for advanced engineering education and research

CLUSTER
LEADING UNIVERSITIES OF SCIENCE AND TECHNOLOGY

EuroTech Universities
Excellence in Science and Technology

IDEA League

NORDIC FIVE TECH

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EXECUTIVE SUMMARY

Universities of science and technology (TU's) have long acknowledged the important contribution of doctoral graduates in the creation of new knowledge. In the past, the training of doctoral researchers was largely tacit and implicit. In more recent years, universities, together with European and national policy makers, have made certain elements of this training more explicit. For example, in 2011 the European Commission published the seven principles of Innovative Doctoral Training (IDT).

With this paper, five associations of universities of science and technology – CESAER, CLUSTER, EuroTech Universities Alliance, IDEA League and Nordic Five Tech – contribute to this ongoing discussion on IDT from the perspectives of their 53 member universities located across Europe. This paper does not necessarily represent the views of all these universities, but it aims to highlight some best practices and challenges that TU's encounter in the development of their doctoral training programmes. The paper aims to stimulate a further in-depth discussion about the future of doctoral training both with key European stakeholders and between the universities themselves. The paper presents a first set of recommendations targeted at universities, as well as European and national policy makers, on how to encourage the further uptake and implementation of IDT models.

Similarly to comprehensive universities, TU's are constantly developing innovative approaches in their provision of doctoral training – particularly in relation to the (three) principles of Research Excellence, Attractive Institutional Environment and Quality Assurance. Faced with the increasing variety of career perspectives of doctoral graduates, TU's have specific experience and models to offer in relation to the (four) principles of Interdisciplinarity, Transferable competences, Exposure to the non-academic sector and International networking.

On the basis of best practice models of IDT across Europe's TU's, the following recommendations are presented:

- Inter-institutional centres for high-quality training on transferable competences, capabilities and skills, such as entrepreneurship, leadership, open science and responsible innovation, should be supported with sustainable funding.

- Industry-driven Public Private Research Partnerships should be developed to increase the exposure of doctoral researchers to industry, including Small and Medium Enterprises.

- The right incentives should be provided to doctoral researchers, as well as to their academic supervisors and to their institutions, in order to ensure that transferable skills training modules are recognized as an integral part of the doctoral degree.

- Industrial and professional doctorates should be further explored, encouraging their wider uptake on a transnational level.

- Funding programmes for Innovative Training Networks should be reinforced through the creation of a platform at European level to discuss and develop guidelines for development of curricula in transferable skills.

- Funding programmes should be strengthened to encourage projects that go beyond the individual scientific disciplines, in order to encourage true cooperation between engineering and natural sciences and social sciences and humanities.

- With the vast majority of doctoral graduates pursuing a career in the non-academic sector, funding agencies should further emphasize innovation, project management, entrepreneurship and other relevant transferable skills in doctoral training programmes.

- Universities and funding agencies should encourage new forms of multilateral collaboration between doctoral researchers to work on the grand societal challenges.

- The European mobility of doctoral graduates should be built upon by increasing opportunities for international tenure-track or tenured position after graduating.

- Universities should share their best practices in encouraging interdisciplinary doctoral theses.

EDITORIAL

Doctoral researchers represent the next generation of scientists and educators. They will fulfill key roles in addressing Europe's grand challenges in health, food security, sustainable energy, green transport, and climate change and contribute to the expansion of the body of scientific knowledge. Much of the related research is conducted at Europe's universities, in particular at universities of science and technology. Their graduate schools address these topics in their programmes which prepare researchers for a range of different career paths - in academia as well as in industry and other societal sectors.

The majority of doctoral graduates in science, technology and engineering pursue a career outside of academia. Doctoral graduates are therefore important actors in industry and other public and private sectors, as well as entrepreneurs or leaders and "intrapreneurs" in industry, government and other sectors. Although a wide variety of statistics have been in circulation, in many countries, such as Germany, approximately 90% of doctoral researchers in these domains leave university immediately after completing their doctorate and start working in industry and other non-academic domains.

Recognizing the importance of science and technology in society and the important roles and career perspectives of doctoral graduates, doctoral training is changing, moving away from its overriding focus on preparing doctoral researchers for an academic career. The challenge remains to balance the basic orientation of the doctorate towards creating new knowledge in a certain discipline or domain with developing competences, capabilities and skills in line with the diverse requirements of society at large.

The European Commission has recognized these challenges by defining seven principles for Innovative Doctoral Training (IDT). The five Associations of Universities of Science and Technology (see Annex 1) who have co-produced the present discussion paper are well aware of related reports and studies prepared in the last decade by the European Commission and other associations, such as EUA and LERU. This paper is their contribution to this debate and will provide information about novel aspects that have been less considered so far.

Europe's universities of science and technology (TU's) work in close collaboration with external partners and naturally follow problem-oriented approaches. Since societal challenges hardly ever follow disciplinary categories, multi- and interdisciplinarity are essential requirements for their research approach. Actively contributing to societal challenges and industrial competitiveness have always been core parts of the TU's missions. Consequently, they have developed appropriate models of doctoral training.

The present discussion paper focuses on the specific challenges faced by universities of science and technology in relation to innovative approaches in doctoral training. We concentrate on four of the seven principles of IDT – Interdisciplinarity, Transferable Skills Training, Exposure to industry and International Networking – as we believe we have good practices and novel approaches especially in the implementation of these IDT principles. We are looking forward to discussing our findings with partners from other universities, with stakeholder organizations and with the European Commission.

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1. SETTING THE SCENE INNOVATIVE DOCTORAL TRAINING AT UNIVERSITIES OF SCIENCE AND TECHNOLOGY

AIMS AND SCOPE OF THIS PAPER

Until the present time, Universities of Science and Technology (TU's) have been somewhat absent in the ongoing discussion on Innovative Doctoral Training (IDT) in Europe. With their activities across the whole research and innovation cycle and with their expertise, the TU's can make important contributions to this discussion. Their expertise has led to the conclusion that models of doctoral training should constantly be reviewed and adapted, as a direct result of TU's mission to address grand societal challenges, their natural proximity to industry and entrepreneurial approaches. With this paper, five associations of universities of science and technology – CESAER, CLUSTER, EuroTech Universities Alliance, IDEA League and Nordic Five Tech (see Annex 1) – aim to make a contribution to this ongoing discussion on IDT from the perspectives of their member universities.

Similarly to comprehensive universities, TU's are constantly developing innovative approaches in their provision of doctoral training – particularly in relation to the (three) principles of Research Excellence, Attractive Institutional Environment and Quality Assurance. This paper rather focuses attention on those (4) IDT principles where the TU's believe they have unique models and wide experience to offer. The subsequent chapters therefore cover the principles of Interdisciplinarity, Transferable competences, Exposure to the non-academic sector and International networking.

For each of these principles, a variety of models are offered in the form of a non-exhaustive list of practical examples in place across our member universities (see chapters and Annex 3 for further detail). The paper concludes with a number of recommendations for policy makers and universities.

There are wide varieties in the models of doctoral training across our 51 member universities. This paper therefore does not necessarily represent the views of the member universities, but is does presents models which have been implemented across the landscape of TU's. Hence, the paper aims to promote discussions both with EU stakeholders and within the TU's on the continuing challenge to develop and adapt doctoral training models to the needs of science, industry and society.

CURRENT DISCUSSIONS ON IDT

In an editorial of a recent issue of SCIENCE, Alan I. Leshner, Chief Executive Officer Emeritus of AAAS, called for rethinking graduate education: "All available evidence suggests that over 60% of new Ph.D.s in science in the United States will not have careers in academic research, yet graduate training in science has followed the same basic format for almost 100 years, heavily focused on producing academic researchers. Given that so many students will not join that community, the system is failing to meet the needs of the majority of students."[1] A similar observation can be made in Europe.

Traditionally, the role of doctoral training has been to develop the candidate's ability to produce new knowledge through independent research and to present and discuss the results in a dissertation and in publications in scientific journals. In many disciplines, completing a doctorate was seen as a first step in an academic career although in some minor examples, such as chemical engineering, a doctorate has always been desirable if not a requirement for employment in industry.

With the development of a more knowledge-based economy, the role of universities continues to evolve. They are seen by governments as key actors supporting industrial competitiveness and improving the quality of life. Next to education and research, services to economy and society and exploitation of research results are seen as the "third mission" of universities. At the same time, in addition to specific activities linked to improving existing and developing new products, processes and services, addressing grand societal challenges call for a supply of research talent able to develop interdisciplinary solutions that also take into account the economic, environmental and social impact of technologies. This is a requirement for all doctoral researchers, whether they pursue a career in academia or in the wide range of the non-academic sector.

DEVELOPMENTS AT UNIVERSITIES OF SCIENCE AND TECHNOLOGY

As part of their mission to address major societal challenges, universities of science and technology promote excellence in order to advance knowledge while at the same time supporting the relevance of research and innovation for society. TU's work in especially close collaboration with external actors in defining problems, designing research agendas as well as developing and implementing solutions. This close interconnection and intense collaboration with external actors has specific implications for the implementation of IDT, as discussed throughout this paper.

Based on actual data at some of our member universities, as well as on the overall perception at others, it is estimated that, of all doctoral researchers, only 10% continue in academic research and/or academic teaching[2] after graduation. Of these, only a small proportion achieve the goal of becoming a professor. In Germany, approximately 90% of doctoral graduates of TU's (Technische Universitäten) leave university immediately after graduation[3] and start working mainly in industry but also in non-university research performing organizations or in other non-academic sectors. While they are not continuing to work as academics, they draw upon the competences, capabilities and skills as well as the aptitudes and principles attained in the course of their doctoral training in their new working environment.

While most of the doctoral graduates enter into non-academic careers some alternative, more "indirect", pathways towards joining the academic staff and becoming a lecturer or professor are fairly typical at TU's, as a direct result of their close relations with industry. Graduates sometimes have a career in industry or in other societal sectors before subsequently being offered an academic position as professor. This approach is also supported by chairs sponsored by industry or other external actors, for example. Due to this variety of career perspectives and the increasing diversity of requirements and options for doctoral graduates, TU's are constantly developing innovative approaches in their provision of doctoral training.

THE PRINCIPLES OF INNOVATIVE DOCTORAL TRAINING

Based on expert advice, the European Commission, based on expert has defined the seven Principles of Innovative Doctoral Training as follows:[4]

1. Research excellence
2. Attractive institutional environment
3. Quality assurance
4. Interdisciplinary research options
5. Transferable skills training
6. Exposure to industry and other relevant employment sectors
7. International networking

Doctoral programmes at universities of science and technology follow approaches that are in many respects in line with these seven principles. Consequently, TU's also face similar challenges as comprehensive universities when implementing these principles in the framework of a doctorate that should not exceed four years.

The Final Report on the Exploration of the Principles for Innovative Doctoral Training, delivered by the Center for Higher Education Policy Studies and Idea Consult for the European Commission in 2011 was put together following an extensive mapping and study visits to numerous (mainly comprehensive) universities across Europe.[5] According to the report, "both quality assurance and attractiveness of the research environment are … building blocks to stimulate research excellence." Universities of science and technology face similar challenges to comprehensive universities in this regard.

However, the European Commission's 2011 Report (see above) refers to the last four principles of IDT – Interdisciplinary Research Options, Transferable skills training, Exposure to industry+ and International networking – as 'surrounding principles'. Whilst universities that contributed to the European Commission's 2011 Report acknowledged that these four principles contribute to IDT, the degree of consent varies.[6] In general, TU's attach great importance to these last four principles. Indeed, at leading universities of science and technology, doctoral training cannot be considered 'innovative' without adopting these principles. The adoption of these principles has generated significant experience and highlighted new challenges for doctoral training. It has created awareness that the TU's should continuously innovate and adapt doctoral training to the needs of the economy and society. The challenges for doctoral training are addressed in the subsequent chapters of this paper.

2. PERSPECTIVES ON INTERDISCIPLINARY RESEARCH OPTIONS

INTRODUCTION

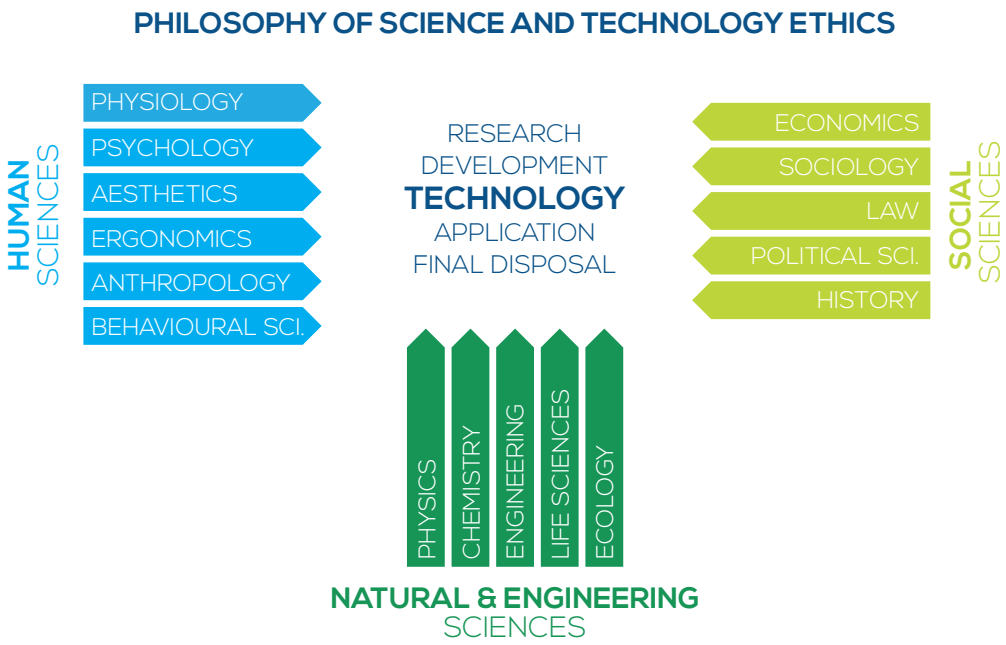
Interdisciplinarity combines concepts, methodologies, approaches, epistemology, terminology, insights, and data of different academic disciplines in order to pursue common scientific interest. It requires a joint research strategy with contributions from and interaction between all participants working in different disciplines.[7] As a longstanding and frequently used descriptor covering a wide range of activities, it is important to recognize that "interdisciplinarity" covers a broad spectrum of research cooperation which is also continually evolving over time. At one end of the spectrum, it might consist of increasing confluence across disciplines and research fields which are relatively close (e.g. bioinformatics, biophysics, mathematical finance, materials science and engineering). At the other end, interdisciplinarity can be a driver for building major new bridges across domains of science and technology - for example across technology, cognition, psychology and sociology leading to game changing advances in digital humanities, social robotics, etc.

Universities have historically been organized according to disciplinary lines, as eloquently expressed in the heading of a 1982 OECD Report "Communities have problems, universities have departments".[8] At the same time, interdisciplinarity is vital in order to truly address the grand societal challenges, as outlined in the Lund Declaration of 2009[9], in the Europe 2020 Strategy and by other writers before that, including for example, by Alvin M. Weinberg.[10]

These highly complex societal challenges call for a comprehensive concept of technology (see below) requiring truly interdisciplinary approaches involving natural and engineering sciences, social sciences and humanities (as outlined in the graph below) and considering – as far as possible – an assessment of the intended and unintended consequences of technology and innovation.

The challenge remains for universities in how to develop a dual structure – organizationally to be "discipline-oriented" and functionally to be "mission-oriented". For accomplishing different missions, different arrangements have to be made that cross departmental and disciplinary lines.

The historical developments of the natural and engineering sciences, social sciences and humanities have followed significant epistemological variations across research disciplines in the ways that they go about generating new knowledge, which need to be understood and respected. At the same time, it should be recognized that funding schemes and their associated rules and regulations, as well as evaluation practices, have similarly evolved in line with these disciplines. Further, career paths and promotion in academia are very much linked to disciplinary activities and assessment by peers in one discipline as well as the respective discipline oriented evaluation criteria of funding agencies and learned journals. These can raise important challenges and build barriers for designing interdisciplinary funding schemes as well as publication strategies.



INTERDISCIPLINARITY:
TOWARDS A COMPREHENSIVE CONCEPT OF TECHNOLOGY[11]

DEVELOPMENTS AT UNIVERSITIES OF SCIENCE AND TECHNOLOGY

The present chapter concentrates on the principle of interdisciplinarity in the context of doctoral training at universities of science and technology (TU's). It covers the implications for organising appropriate research environments at graduate schools, as well as for defining the appropriate qualifications of the doctoral candidate.

TU's are arguably more adept at reducing or overcoming barriers to interdisciplinarity, both in terms of their research cultures as well as in terms of the nature of the knowledge that they seek to generate. Capable of acting across the full research and innovation chain – and in cooperation with industry - the results of knowledge driven frontier science are typically taken up within these institutions' engineering departments and developed towards results that may lead to innovation. Influenced by their institutional framework, scientists and engineers, including at doctoral level, generally adopt a "problem solving" orientation – often these problems are not confined within a single discipline but are pluridisciplinary; combining different but related disciplines of natural and engineering sciences such as mathematics, physics, chemical engineering, mechanics, or production engineering and material science.

Engineers have to take decisions between different possible alternative solutions on the basis of well-chosen sets of criteria and values that go beyond technological functionality but encompass aspects such as economic efficiency (micro-economic), prosperity and wealth (macro-economic), environmental quality, security and safety, health, personal development, societal quality.[12] Professor Jeroen van den Hoven (TU Delft) has expressed that very well by saying: "Technical systems and innovative technology are the solidification of thousands design decisions."[13]

The embedding of doctoral training in an interdisciplinary research environment must take into account different cultures of publication across various disciplines. While in some disciplines early publication of results is encouraged, others favour a more delayed approach. There are also important differences in the type of publications preferred. Where research involves the private sector, Intellectual Property Rights (IPR) considerations play an important role. Since the career progression of many doctoral researchers is strongly influenced by their publications record and since their academic supervisors are often engaged in fierce competition to publish, these differences can provide a real challenge for true interdisciplinary cooperation.

While promoting interdisciplinary research, it is crucial that the institution also provides doctoral researchers with the opportunity to acquire an excellent disciplinary foundation. The challenge for Innovative Doctoral Training programmes is to continually ensure an appropriate balance between excellent discipline-based foundations and the capacity for working in interdisciplinary teams or across disciplines. That requires access to transferable competences, capabilities and skills that will be described in the next chapter.

SOME PRACTICAL EXAMPLES

The Exploratory Research Spaces (ERS) at RWTH Aachen University promotes interdisciplinary research between experienced scientists and doctoral researchers. The research is performed by doctoral candidates of at least two disciplines. ERS also provides training on the management of interdisciplinary projects and working in interdisciplinary research teams.

http://www.rwth-aachen.de/cms/root/Forschung/Forschen-an-der-RWTH/Angebote-fuer-Forschende/~ohy/ERS-Angebote/?lidx=1

At **University College Dublin (UCD),** interdisciplinary doctoral programmes are created where groups of doctoral supervisors from different disciplines work together to identify themes of common interest. They create a coherent shared experience for their doctoral researchers by establishing a programme of advanced education, training and research.

http://www.ucd.ie/t4cms/UCD_ThematicProgrammes-science_eng_tech.pdf

At the **Technical University of Munich (TUM) the International Graduate School of Science and Engineering** introduced a novel dimension to interdisciplinary doctoral training and international research. Flexible project teams collaborate in interdisciplinary research across all fields including natural science, engineering and medicine.

http://www.igsse.tum.de/

At the **Munich Center for Technology and Science (MCTS)** of the same university, scientists and engineers are working together with social scientists, historians and philosophers focusing their research on specific technological areas like energy or mobility or on basic questions such as risk, uncertainty or digitalisation.

http://www.mcts.tum.de/en/startseite

Technology and engineering are by their very nature interdisciplinary which is presented e.g. by the interdisciplinary doctoral training in materials science and nanotechnology at **Poznan University of Technology** that ensures true trans-faculty, interdisciplinary cooperation. The aim is to develop a unique model of training in methodologies of research, development of new scientific competences, acquiring new practical skills and exchange of know-how, with focus on application and commercialization of the results.

http://www.isd-n.put.poznan.pl/index.html

The programme of the Doctoral College “Environmental Informatics” of **Technische Universitaet Wien** addresses that new interdisciplinary research field that aims at facilitating decisions regarding social, economic, ecological, and environmental goals based on a variety of information technology measures. The doctoral college provides a collaborative framework for doctoral researchers addressing environmental problems by utilizing synergies from different methods from the fields of informatics, geo-information, simulation, statistics, visualization, energy research, and architecture.

http://ei.infosys.tuwien.ac.at/

3. PERSPECTIVES ON TRAINING IN TRANSFERABLE COMPETENCES, CAPABILITIES AND SKILLS

INTRODUCTION

Transferrable skills are defined by the European Commission as "...skills learned in one context (for example research) that are useful in another (for example future employment whether that is in research, business etc.). They enable subject- and research-related skills to be applied and developed effectively. Transferable skills may be acquired through training or through work experience."[14]

Examples of transferable skills include interpersonal skills, organizational skills, research competences, cognitive abilities, communication skills and enterprise skills.[15] These are accompanied by personal qualities and attitudes such as openness, creativity, curiosity, reflectivity, empathy, interest, receptivity, tolerance, and responsibility.[16] It should be emphasized that these examples are not supposed to be a comprehensive list and must be flexible. According to current discussions within universities and among EU stakeholders, the portfolio of required competences is broadening to include fields such as technology assessment, responsible research and innovation and open science.

As the OECD stated in 2012, "Transferable skills can play an important role in supporting researchers' diverse career paths, ultimately promoting better research outputs and helping underpin innovation and economic growth. These skills have attracted more attention over time, as non-academic employment opportunities grow and research becomes more Interdisciplinary and international."[17]

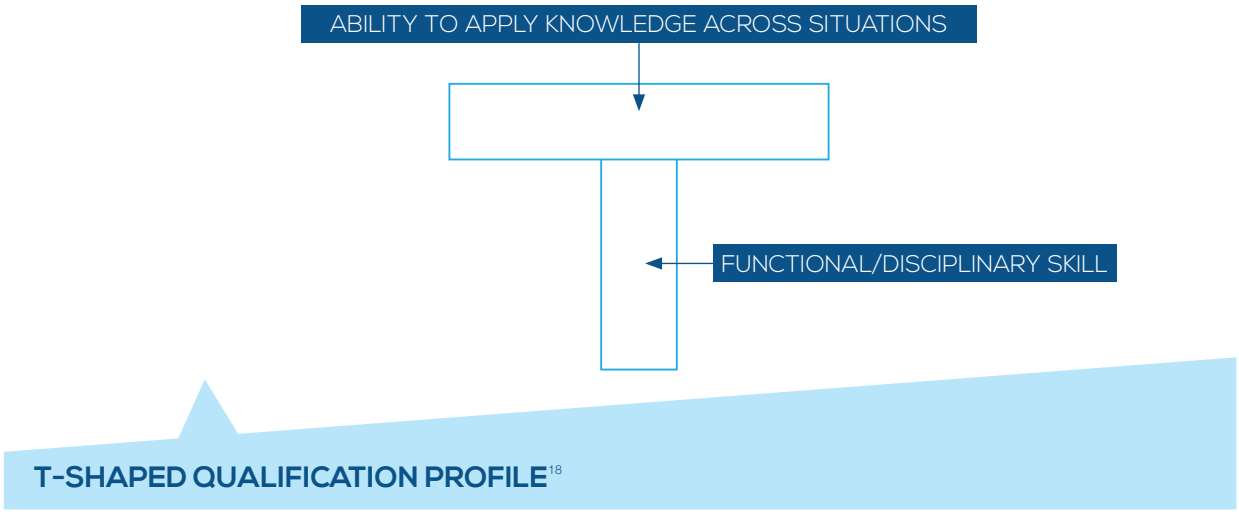
The breadth of training in transferable competences, capabilities and skills on offer must provide doctoral researchers with ample choices tailored to the area and topic of their research and to the individual career path that they wish to pursue. These choices should be offered within a structured and professional comprehensive training framework.

In the past, it was often assumed that doctoral researchers will naturally develop both the ability to carry out independent research and also acquire the attitudes, virtues and personal qualities of a researcher. A major challenge for those who are responsible for increasing doctoral researchers' transferable skills is to ensure that the training offered is strongly informed by real-life needs across the range of careers pursued by doctoral researchers.

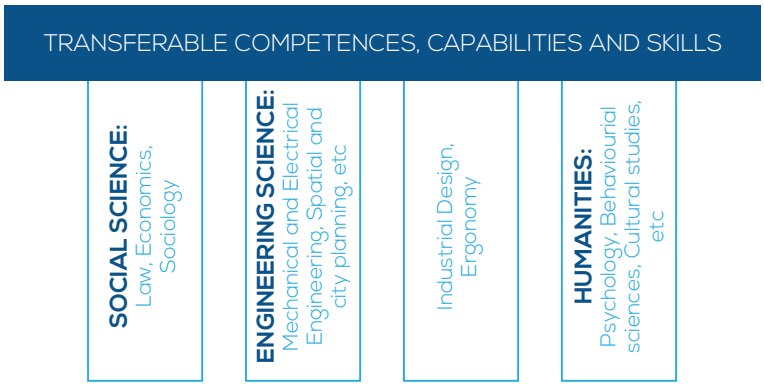
DEVELOPMENTS AT UNIVERSITIES OF SCIENCE AND TECHNOLOGY

The present chapter concentrates on the principle of transferable competences, capabilities and skills in the context of doctoral training at universities of science and technology (TU's).

In order to engage in true interdisciplinary research (see previous chapter), developing transferable abilities must accompany the acquisition of in-depth expertise in a particular field. The first diagram on the next page represents a T-shaped qualification profile of the doctoral researcher, whereby the related competences, capabilities and skills are complemented with both disciplinary "depth" and "inter-disciplinary" breadth.



T-SHAPED QUALIFICATION PROFILE[18]



EXAMPLE: A POSSIBLE INTERDISCIPLINARY TEAM OF MEMBERS WITH T-PROFILES
E.G. IN THE AREA OF AUTOMOTIVE ENGINEERING

The aim is that the doctoral researcher achieves this T-shaped qualification profile. The vertical bar represents the specialization and expertise in a certain discipline or domain. The horizontal bar represents the openness, interest and curiosity towards other disciplines and domains as well as the competences, capability and skills to work as a professional in different environments. With interdisciplinary teams becoming an increasingly strong characteristic of the engineering sciences, TU's have responded to the need for the accompanying new set of competences, capabilities and skills through their doctoral training programmes. Across the TU's, respective courses have been on offer as part of the graduate schools mandatory centrally organized training programme.

In order to remain innovative and responsive to change, TU's regularly review and refresh their doctoral training programmes. For example, the rapid growth in the production of digitized data and the unprecedented move towards open science are driving educational developments at doctoral level. These new developments call for new competences, capabilities and skills, including the ability for young

researchers to manage their data and to disseminate their research appropriately and to engage with society at large on the grand challenges.

EU strategic objectives, including the Europe 2020 strategy (2010) and Horizon 2020 define the need for a better alignment of research and innovation with societal values, needs and expectations and for a comprehensive approach towards Responsible Research and Innovation (RRI).[19] This requires the next generation of researchers to be equipped to deal with wide ranging issues, from public engagement and open access to technology assessment, ethics and gender related matters. New training materials as well as learning environment such as interdisciplinary projects integrating technology assessment and responsible research and innovation are being introduced at leading TU's to meet the needs of many different users, from doctoral researchers, to data managers, librarians, funders and graduate schools. A discussion about how RRI can and should be considered in the training of doctoral researchers should be launched among universities across the European landscape.

A specific mission of TU's is to train innovative and entrepreneurial doctoral researchers, who are apt to convert knowledge and ideas into new or improved technologies to become innovations introduced into the market and society at large. As well as offering a wide range of both curricular and non-curricular courses in entrepreneurship, TU's also provide support measures for young entrepreneurs, whilst also promoting an entrepreneurial culture among doctoral researchers, academic staff and university administrations.[20]

SOME PRACTICAL EXAMPLES

Many universities of our associations offer structured training in transferable competences, capabilities and skills encompassing interpersonal skills, organizational skills, research competences, cognitive abilities, communication skills and enterprise skills or sustainable development, and research integrity. Examples are the Doctoral School for Engineering and Science at **Aalborg University**, the courses on Generic and Transferable Skills at **Chalmers University of Technology**, the Graduate Academy at **Dresden University of Technology**, and the PLACEDO Programme at **Bucharest Polytechnic University**.

http://www.phd.teknat.aau.dk/
http://www.chalmers.se/en/research/doctoral-programmes/Pages/GTS-courses.aspx
http://tu-dresden.de/die_tu_dresden/zentrale_einrichtungen/graduiertenakademie
http://placedo.pub.ro/doctoranzi_UPB/

The **Cortona Week, organized within the IDEA League framework**, is a platform that nurtures wider scopes of thinking, competence and creativity for all. By exposing and extending the expertise of doctoral researchers from engineering to natural sciences, humanities and arts, it strives to foster individual artistic, spiritual and humanistic capabilities.

http://www.cortona.ethz.ch/

Entrepreneurship training facilities at the **EuroTech Universities** are widely available to support doctoral researchers to develop their own innovative ventures. This includes providing a favourable environment and framework conditions for developing creative ideas and seeking to attract the necessary funds to maximize the value of commercially viable interventions with both a strong technological and an international market potential. The EuroTech Universities' EUROPEAN VENTURE PROGRAMME, funded by the ERASMUS+ programme offers doctoral researchers the opportunity to 'Become an Entrepreneur in 12 days!' through exclusive access to entrepreneurship expertise and networking resources available across the four universities.

http://eurotech-universities.eu/innovation-and-entrepreneurship/

Aalto University played an active role in setting up the doctoral training centre in the frame of the Helsinki node of Digital Knowledge and Innovation Community of the European Institute of Innovation and Technology (EIT). In the centre, training programmes in innovation and entrepreneurship for doctoral researchers are offered.

http://doctoralschool.eitictlabs.eu/doctoral-training-centres/dtc-helsinki/

In the frame of the FP7 project FOSTER - Facilitating Open Science Training for European Research – TU Delft and the Danish Technical University (DTU) together with eleven other partners across eight different countries, aim to produce a European-wide training programme to help doctoral researchers, librarians and other stakeholders to incorporate Open Science approaches into their existing research methodologies.

https://www.fosteropenscience.eu/

4. PERSPECTIVES ON EXPOSURE TO INDUSTRY AND OTHER RELEVANT EMPLOYMENT SECTORS

INTRODUCTION

Exposure to non-academic sectors can provide significant benefits not only to doctoral researchers themselves but also to their home institutions as well as to research and innovation intensive employment sectors. In many ways, these benefits are similar to those provided by training in transferable competences, capabilities and skills. But while the latter training is primarily, if not exclusively, organized and implemented within the candidate's home institution, exposure to non-academic sectors is influenced by the specific profile of the university as well as many other factors such as national legislation, education and training cultures and the existence of knowledge intensive employment sectors in the vicinity. Exposure to "real world" situations provides excellent opportunities for developing important experiences and insights following an old proverb: "Tell me and I will forget, show me and I will remember, involve me and I will understand".

A significant proportion of doctoral training programmes are carried out by talented young individuals during those periods of their life which are especially formative in the development of their scientific potential, creativity and out of the box thinking as well as world views and ethical engagement. Direct exposure to the challenges as well as the opportunities in "real life" non-academic sectors of the economy and society at large is more than ever relevant in a world that is increasingly characterized by networking, connectivity, inter-sectoral mobility and wide access to knowledge.

Furthermore, opportunities for exposure to industry and other sectors can directly enhance the attraction of doctoral training to young talented individuals, many of whom are likely to be in direct competition with those of their peers who have gained more hands-on experience outside of academia during the same period. This is especially important for a large proportion of doctoral researchers who go on to pursue careers outside of academic research. However, it is also relevant for those that embark on an academic career because it supports their understanding of the role of the university in society as well as it creates links to non-academic sectors that will be useful for them later on.

Exposure to industry and other non-academic sectors is generally the most controversial IDT principle as well as the one demonstrating the greatest difficulty and variability in terms of its implementation.

Its controversial nature is underlined by the continuing debate as to whether or not this constitutes an appropriate or desirable component of doctoral training. At the same time, the balance of arguments clearly varies across different doctoral research fields - from directly job specific fields such as engineering and medicine to more innately academic study fields in basic science and in the humanities.

An important challenge in terms of implementation arises from the variety of actors – both within and outside of the doctoral researchers' home institution - which need to be involved. These actors include the candidate's supervisor, the university leadership and the external organization(s) which is/are associated with the doctoral candidate's involvement.

There is a broad variety of mechanisms for exposing doctoral researchers to industry and other non-academic sectors. This diversity should be nurtured; actually, it holds for all the seven IDT principles that they are not amenable to "one-size-fits-all" approaches. An unintended consequence of this variety is that it is especially challenging but at the same time interesting to identify best practices or to promote mutual learning.

DEVELOPMENTS AT UNIVERSITIES OF SCIENCE AND TECHNOLOGY

Within the higher education sector, IDT principle on Exposure to the non-academic sector is of particular relevance to universities of science and technology (TU's). In leading, research intensive TU's, doctoral training can cover a broad spectrum ranging from "blue-sky", investigator driven research (e.g. supported by the European Research Council or national research agencies) to doctoral training in various branches of engineering more close to application. In the case of the latter, deep collaboration with external partners is often an essential component of IDT - closely intertwined with the key IDT principle of research excellence.

More and more traditional linear technology transfer concepts are extended towards co-creation and co-development of technologies. In the frame of doctoral programmes different forms of cooperation with and support from external partners, especially industry, are applied at TU's. For instance, doctoral candidates have the opportunity to do part of their research work in industry as well as joint supervision by the university and the partner organization.

TU's across Europe have been particularly successful in the take-up of industrial doctorates, e.g. in Denmark, Germany, Italy and the Netherlands. An industrial PhD is an industrially focused research project carried out in collaboration between a company, and Industrial PhD researcher and a university. The doctoral researcher is employed by the private sector and enrolled at the university. They share their working time between the company and the university, spending all the work time on the industrial PhD project. On the one hand, the company has access to a high quality research project which can lead to commercial gains.

On the other hand, the industrial doctorate can lead to even strong cooperation between the university and the company.

SOME PRACTICAL EXAMPLES

Budapest University of Technology and Economics (BME) together with Eötvös Loránd University (ELTE) established the Doctoral Training Centres (DTC) in the Budapest node of the EIT Digital offering a unique opportunity for young researchers who wish to pursue doctoral training, especially in communication software and system performance in an innovative environment in close cooperation with industries. Budapest DTC provides full integration of both technical and business aspects of ICT.

http://doctoralschool.eitictlabs.eu/doctoral-training-centres/dtc-budapest/

Universitat Politècnica de Catalunya works closely with industrial partners to implement the Industrial Doctorate Plan. Doctoral researchers receive training in cross-cutting areas as project leadership, coordination and management; transfer of research results; new business development as for example sources of funding, business management; d) patents, industrial and intellectual property. Courses are given by the university and by the industrial partners. The doctoral researchers are employed by companies participating in the programme.

http://doctorat.upc.edu/?set_language=en

The Impuls Program at **Eindhoven University of Technology (TU/e)** co-funded, together with its partners in industry and research, 250 extra PhD researchers in 2014-2015. Through this initiative, TU/e and its partners aim to strengthen the research partnerships in focus areas such as energy, health, mobility, high-tech systems, data science and materials.

https://www.tue.nl/en/university/working-at-tue/tue-impuls/

The Industrial doctorates of **Politecnico di Milano and Politecnico di Torino** offer the opportunity to start industrial doctoral paths co-supervised by companies and external institutions. The industrial PhD programme also allows companies to train their employees, already engaged in highly-qualifying activities, in the framework of a doctoral programme.

http://www.dottorato.polimi.it/en/looking-for-a-phd/call-for-positions-and-scholarships/industrial-phd/executive-phd/
http://dottorato.polito.it/en/industrial_phd_programme/

The Doctoral Programme on Leaders for Technical Industries (LIT) at the **Faculty of Engineering at University of Porto** is a focus area of the MIT Portugal Programme that aims to develop a new paradigm for engineering education that closely links high quality research to novel curricular programmes and to promote an entrepreneurial approach to knowledge-based manufacturing and competitive product development. It is dedicated to generate new scientific knowledge and new engineering solutions to create and capture value in highly competitive industrial sectors. The scope and associated proposals of the program were defined and prepared in fruitful collaboration between faculty and industry leaders.

http://www.mitportugal.org/engineering-design-and-advanced-manufacturing/doctoral-program.html

Technische Universitaet Wien and the Wiener Stadtwerke Holding AG (Vienna Public Utilities Company) together established the Urban Energy and Mobility Systems Doctorate College (URBEM-DK) funding ten doctoral researchers for developing sustainable energy and mobility concepts for a Smart City Vienna by 2016. The doctoral researchers enjoy joint supervision from the university and the industrial partners and are involved in interdisciplinary praxis oriented cooperation.

http://urbem.tuwien.ac.at/home/EN/

5. PERSPECTIVES ON INTERNATIONAL NETWORKING

INTRODUCTION

The grand challenges of our age are no longer bounded to national borders or continents. These challenges are also highly complex, carry potential major impacts and are characterized by important uncertainties.

International and global challenges require international and global actions and solutions in terms of shared understanding as well as in the development of policies, actions and technical solutions. This calls not only for multidisciplinary research teams combining complementary intellectual, methodological and material resources, but also for researchers with strong international orientation and capabilities to function in multi-cultural environments.

The last decades have seen a strong increase in international cooperation across science, technology and innovation:[21]

- In 2008, 35% of articles published in international journals were collaborative, up from 25% in 1998[22]
- For Germany, in the same period, the proportion of national publication output produced in collaboration with other countries increased from 32% to 48%[23]
- The research team size on scientific papers has almost doubled since 1950 – increasing from 1.9 to 3.5 authors per paper[24].

Free movement within Europe provides an invaluable foundation for international networking in Innovative Doctoral Training. This is becoming an increasingly important comparative advantage in the fierce global competition for talent. Nevertheless, Europe is still falling behind the USA in research collaboration and researcher mobility.[25] The difference in academic placements and careers between the different European countries limits European mobility for tenure-track and tenured positions. Some countries have highly centralized and sometimes bureaucratic mechanisms for allocating university positions. It is highly desirable for the development of European Research Area that a single European academic job market is truly developed. This would insure that each researcher can find the most suitable university across all 28 countries of the Union.

The continuing globalization of science and the opportunities provided by digital technologies increase the challenges as well as the new possibilities for international networking within Innovative Doctoral Training. Whatever the eventual career path of doctoral researchers might be, collaborating across different cultures demands a deep mutual understanding and respect. It also demands the skills to communicate and work in multicultural teams. Training in social skills is key to provide doctoral researchers the necessary tools to improve their capabilities succeed in international research environments. Training in international networking is supposed to strengthen the doctoral researchers' experience working with multicultural teams.

Although the challenges are on a world scale, access to knowledge and data is not something which can be taken for granted world-wide. Collection of data in different languages, via diverse channels and institutes prove a challenge in itself when borders are

present. Working on the same topic, from different perspectives and in an atmosphere mutual trust can open access to data previously not available or understandable. New international programmes for doctoral training can help to stimulate the accessibility of data and knowledge.

Last but not least, science diplomacy is an increasingly important feature of international relations. Arguably, EU R&D framework programmes are among the most open in the world in terms of welcoming third country participation in collaborative projects, promoting inward and outward researcher mobility beyond the EU's borders as well as entering into more formal S&T Cooperation agreements with a large number of third countries. These practical arrangements are being significantly boosted at the political level by Commissioner Moedas' clear commitment to further strengthen EU research's openness to the world. Clearly, the friendships and collaborations forged by doctoral researchers within – and sometimes across - HE institutions in Europe are key building blocks not only for scientific cooperation but also for greater mutual understanding and respect for the common good. There are no magic bullets for combining top-down, political arrangements with bottom-up, often spontaneous connections. Nevertheless, there is an unprecedented need and perhaps a unique opportunity to encourage the latter and to highlight possible fora/platforms for the future (e.g. alumni networks etc.).

DEVELOPMENTS AT UNIVERSITIES OF SCIENCE AND TECHNOLOGY

International networking lies at the heart of the universities of science and technology. In a globalizing world, TUs encourage maximum international exposure of their doctoral researchers. Promoting European and international collaboration and networking has been an important driver in the creation and functioning of the European associations of universities of science and technology themselves. These alliances offer preferred European and international partnership frameworks, in which collaboration is fostered in an environment of mutual trust. Furthermore institutionalized mobility and exchange during an IDT programme have helped to provide an excellent framework for doctoral researchers to visit various partners and build personal, international networks. These networks can help young researchers to find their way in the complex European Research Area and beyond.

It would be important to highlight that International networking is not only fulfilled through international mobility and physical exchange. The recruitment of international doctoral researchers is steeply increasing across European TU's. As an example, TU Delft recruits 60-80% of its doctoral researchers from outside of the Netherlands. This tendency gives rise to a range of new challenges, from the selection of doctoral researchers, intercultural communication and cultural specific characteristics of conducting research.

TU's have experimented different models for bringing together international project teams for interdisciplinary doctoral projects. For instance, within the International Graduate School for Science and Engineering[26] at the Technical University of Munich, doctoral researchers work in international teams of four across scientific disciplines. With half of the team physically located within TUM and the other half outside of Germany, the doctoral researchers embark on an extensive exchange over the period of the doctoral training. The participating postdocs, supervisors, research chairs and the research institutions themselves play a key role in facilitating international partnerships key to the success of these activities.

TU's are regularly reviewing their approaches doctoral training programmes to ensure they offer the best international opportunities to their doctoral researchers. This includes building upon collaborative arrangements with individual professors or doctoral schools at other universities, joint supervision, co-tutelle or bi-national doctorates, or joint degrees. Doctoral schools have been created to integrate these approaches institution-wide. However, these international collaborative arrangements are usually on an inter-university level. While doctoral researchers at research intensive TU's have privileged exposure to the non-academic sector, especially industry (see previous chapter), these schemes are rarely transnational. Developing transnational schemes for exposure to industry in Innovative Doctoral Training would be of benefit to doctoral researchers, to their institutions, as well as to industrial partners.

SOME PRACTICAL EXAMPLES

The CLUSTER high level summer schools for doctorates take place every year, alternately in China and Europe, in the frame of the Sino-EU Engineering Education Platform (SEEEP), a collaboration between 18 Chinese universities and the 12 CLUSTER members. The schools bring professors and doctoral researchers from the highest level together to come up with solutions to the grant societal challenges in multidisciplinary and multinational teams. The challenges are important to China and Europe and include topics as energy transitions, health, active aging or raw materials. Active participation from Industry and municipalities is required for assignments which will be solved by PhD's in multidisciplinary and multinational teams. Organized by four universities, it is open to all 30 members of the Sino-EU Engineering Education Platform.

http://clustersymposium.org/sino-eu-engineering-education-platform/

The Ethics and Technology doctoral programme at the 3TU's in Netherlands is an internationally interdisciplinary oriented programme by TU Delft, Eindhoven University of Technology and the University of Twente integrating technology, social sciences and humanities. Doctoral researchers in the programme are required to spend three to six months abroad under supervision of a local researcher, to broaden their horizons and network, and follow additional courses in Australia or the USA.

http://www.utwente.nl/en/education/post-graduate/tgs/programmes/et/ethics-technology/

Politecnico di Milano (PoliMi) offers a broad spectrum of international doctoral programmes in different formats such as Joint Doctoral Degrees with universities in Australia, Chile, and the USA, Double doctoral degrees with partners in China, Israel, Japan, Qatar and the USA, and Double Doctoral Thesis with universities in Canada, China, Colombia and the USA. In addition, PoliMi utilizes different European and international programmes for attracting doctoral researchers such as the Innovative Training Networks (ITN) - Marie Curie Actions, Erasmus Mundus Projects, or the China Scholarship Council (CSC), the Brazilian Science without Borders (CSF), and the Vietnam International Education Development (VIED).

http://www.dottorato.polimi.it/en/looking-for-a-phd/international-programmes/

Information Technologies for Business Intelligence Doctoral College Erasmus Mundus Joint Doctorate (IT4BI-DC) is a programme involving three CESAER universities - **Universitat Politècnica de València, Technische Universiteit Eindhoven and Ecole Polytechnique Fédérale de Lausanne** – and four other European universities as well as international partner universities from Brazil, Colombia, Lebanon, and the USA. The programme covers the total range of topics needed for future Business Intelligence scenarios. The doctoral candidates are subject to research mobility, having the opportunity for researching in associated universities and industry partners.

https://it4bi-dc.ulb.ac.be/about

6. CONCLUSIONS AND RECOMMENDATIONS

GENERAL REMARKS

With this paper, five associations of Universities of science and technology (TU's) – CESAER, CLUSTER, EuroTech Universities Alliance, IDEA League and Nordic Five Tech – aim to make a first contribution to the ongoing discussion at European level on Innovative Doctoral Training from the perspectives of their member universities. TU's face many similar challenges as more comprehensive universities – for instance, in relation to implementing the IDT principles of Research Excellence, Attractive Institutional Environment and Quality Assurance. This paper has focused on those IDT principles where TU's have specific experience and models to offer – in relation to Interdisciplinarity, Transferable competences, Exposure to the non-academic sector and International networking.

Throughout this paper, it has been demonstrated that TU's central mission to address grand societal challenges creates an institutional setting which is conducive to an interdisciplinary research environment and close collaboration with the non-academic sector, particularly industry. This unique position of TU's has strongly influenced the ongoing development of their doctoral training programmes, ensuring that their doctoral researchers are equipped with the appropriate set of transferable capabilities and skills, in order to respond to the rapidly evolving needs of the global economy and society at large.

TU's models of innovative doctoral training are reflected in their strong uptake of funding under the EU Marie Sklodowska Curie Innovative Training Networks. These grants provide excellent incentives for doctoral researchers across Europe to work together and collaborate with industry on excellent research projects in which the field can be defined in a bottom-up manner.

The topics covered in this paper are illustrated by practical examples in the text and in Annex 3. It should be noted that these examples covered only a small selection of practices across our member universities. With this paper, it is now timely to gather an inter-university discussion forum to examine best practices and challenges with regards further expansion and improvements in the future, with particular focus on the four principles of Interdisciplinary research options, Transferable skills training, Exposure to industry and International networking.

RECOMMENDATIONS

In order to enhance the wider uptake and further development of these models of innovative doctoral training, the following considerations should be discussed and taken into account:

1. Funding programmes, including at EU level, should raise their ambition to encourage projects that go beyond individual scientific disciplines. For instance, at the present time, the Marie Sklodowska Curie Innovative Training Network (MSCA ITN) proposals are allocated to one of the eight main evaluation panels, organized according to broadly identified scientific disciplines. In order to encourage ambitious projects that go beyond

individual scientific disciplines, the European Commission is encouraged to set up the corresponding interdisciplinary evaluation panels. In addition, TU's call upon the European Commission to pilot a funding scheme for ambitious Innovative Doctoral Training Networks which are truly open to interdisciplinarity, requiring project applicants to integrate two or more scientific disciplines in their proposal. Such incentives are vital to encourage true cooperation between engineering, natural and social sciences.

2. Universities are encouraged to exchange on the organization of interdisciplinary doctoral theses within and across universities. Defining and sharing different models of best practice is vital in ensuring their wider uptake across Europe. In order to initiate this process, seven TU's are visiting the Technical University of Munich in autumn 2015. A delegation existing of the Heads of Doctoral Schools, vice rectors, deans and HR directors will gather in a seminar in which they exchange in depth the components of the doctoral training programs.

3. TU's recognize the importance of inter-institutional centres (overarching structures) for high-quality training on transferable skills and competences such as entrepreneurship, leadership, open science and responsible innovation as a core part of doctoral training and as a potential cost-effective vehicle to this end. Their long-term establishment based on sustainable funding and enduring quality assurance measures will ensure a continuous improvement of the personal, professional and interpersonal capabilities of future doctoral researchers.

4. TU's have thus far greatly benefitted from the MSCA ITNs as a means to encourage international networking, as well as exposure to the non-academic sector. They have also been particularly successful in transfer best practices in transferable skills courses. TU's would encourage the European Commission to continue supporting those networks that include the latest developments in transferable skills training. Further, TU's would welcome the creation of a platform at European level to discuss and develop guidelines for development of curricula in transferable skills. Best practice examples could be included with targets for minimum required provision of transferable skills training to doctoral researchers over the course of their thesis.

5. It remains a challenge to ensure that an increasing demand for transferable competences, capabilities and skills is truly in line with the classic three to four year duration of the doctoral degree. In order that transferable skills training modules are fully recognized as an integral part of the doctoral degree, the right incentives should be provided to doctoral researchers, to academic supervisors and their institutions. Allocating ECTS (European Credit Transfer System) to transversal skills courses represents one possible way to increase recognition of transversal skills courses as a core part of doctoral training. Furthermore, it is important that the right approaches to teaching and learning are applied in order to ensure acceptance as well as real adoption and integration by providing opportunities for experiencing the practical relevance of these elements of doctoral training.

6. With the vast majority of doctoral graduates going on to work in the non-academic sector, funding agencies of doctoral training should advocate innovation, project management and other business elements as core parts of their calls for proposals.

7. Industrial and professional doctorates should be further explored and where possible aligned with similar degrees, encouraging their wider uptake and recognition on a transnational level. Programmes that enable pilots in which universities can experiment with cooperation models with the non-academic sector, including physical hubs, are welcome.

8. The European Commission has launched an increasing number of industry-driven research Public Private Partnerships a view to developing new technologies, products and services to give European industry a leading position in global markets. These partnerships should be encouraged to promote pilot schemes to increase the exposure of doctoral researchers to industry. These pilot schemes should include a study of the challenges and opportunities (including incentives) for the SME sector to enhance its participation in relevant schemes.

9. Universities and funding agencies should encourage new forms of multilateral collaboration between doctoral researchers to work on the grand societal challenges. Incentives can include the possibility for doctoral researchers to organize their own summer schools on a certain theme, encouraging international networking and a natural interdisciplinary approach. The trust-based inter-institutional alliances of like-minded universities, such as CLUSTER, EuroTech Universities Alliance and IDEA League, have been conducive to this international collaboration between researchers of all levels. The development of a platform for the exchange of best practices across the whole of Europe should be further promoted in this regard.

10. While training and mobility opportunities across the EU Framework Programmes, most notably MSCA, have been an undoubted success, the European mobility of doctoral graduates could be further improved. For example, it is still difficult for doctorates to find an international tenure-track or tenured position after graduating. Furthermore, strengthening Innovative Doctoral Training "infrastructures" such as shared doctorate courses, funding for mobility, access to summer schools etc. is a necessity to provide excellent tools for doctoral researchers to create their own international network.

The contributors to this paper look forward to fruitful discussions for the benefit of the doctoral researchers actively engaged at the member institutions of the partner associations. In follow-up discussion, we aim to achieve a more complete picture of innovative models of doctoral training across the 53 member institutions of the five associations of universities of science and technology.

ANNEX 1

ABOUT THE FIVE ASSOCIATIONS OF SCIENCE AND TECHNOLOGY

The present report has been prepared jointly by five university associations - CESAER, CLUSTER, EuroTech Universities Alliance, IDEA League and Nordic Five Tech - that are the principal channels for connecting leading universities of science and technology to the EU policy landscape. While each association has its own specific history, rationale and focus, they recognize the necessity to speak with a strong and coherent voice on the European landscape and to work together on issues of common interest and relevance.

CESAER, the Conference of European Schools for Advanced Engineering Education and Research, is member of the ERA Partnership between the European Commission and stakeholder organisations and works closely with the above mentioned partner associations that are formed by smaller groups of its member institutions. Together they contribute to a number of the key priorities highlighted in the Commission Communication on ERA of 17 July 2013. The completion of ERA is seen as of the highest importance and the associations are committed to supporting the efforts of the Commission in that gradual process by implementing ERA actions.

Established in 1990, CESAER is a non-profit international association of 50 European universities of science and technology as well as engineering schools/faculties at comprehensive universities and university colleges. 40% of the 50 top higher education institutions participating in FP7 are CESAER member institutions.

CESAER stands for maintaining and promoting the highest quality standards in knowledge creation and transfer and for scientific excellence in engineering education and research. CESAER member institutions promote innovation through close cooperation with the private and the public sector in order to ensure the application of cutting-edge knowledge in industry and society. CESAER initiatives are implemented by Task Forces and Working Groups in the areas such as human resources, gender equality, entrepreneurship, knowledge transfer, open access and cross-border cooperation.

http://www.cesaer.org/
http://ec.europa.eu/research/era/partnership_en.htm

CLUSTER (Consortium Linking Universities of Science and Technology for Education and Research) was also established in 1990 and is a consortium of 12 European universities with associate members from around the world. CLUSTER is an active platform in the promotion and creation of frameworks aiming to tackle grand societal issues. CLUSTER evolved from being focussed only on engineering education to be, nowadays, acting on the so-called knowledge triangle comprising education, research and innovation. Main activities are joint master programmes as well as doctoral programmes between European partner institutions but also with Chinese universities.

http://www.cluster.org/

Established in 2011, the **EuroTech Universities Alliance** is a strategic partnership of four leading European universities of science and technology. Working together, they are committed to finding technical solutions which address the major challenges of modern society. Their intensive collaboration across research, education and innovation supports the EU's goals of smart, sustainable and inclusive growth.

More than 9,000 doctoral researchers are currently registered across the four EuroTech Universities' graduate schools. Within the framework of the Alliance, the EuroTech Universities' joint doctoral activities include a common database of doctoral courses, a shared educational platform in the field of Economics and Management of Innovation and Entrepreneurship and co-organized summer schools in areas of complementary research expertise. Further, EuroTech Universities' joint European Venture Programme, funded through the ERASMUS+ Programme, is open for doctoral researchers to 'Become an Entrepreneur in 12 days!' through privileged access to the entrepreneurship expertise and networking resources available at the four EuroTech Universities.

http://eurotech-universities.eu/

The **IDEA League**, founded in 1999, is a network of four universities of technology and science. The network's joint activities in education, research and quality assurance, as well as joint participation in EU programmes and initiatives make IDEA League a model of European cooperation. Together, the partner universities create added value by pooling resources for collaborative and complementary programmes for our students, researchers and staff. Examples of activities are student exchange, summer schools as well as joint doctoral schools such as in the areas of ageing, quantum information processing, and urban systems. In the European Venture Programme, Master students can present their business ideas at different partner institutions.

http://www.idealeague.org/

Nordic Five Tech (N5T) is an exclusive, strategic alliance of the five leading technical universities in Denmark, Finland, Norway and Sweden. N5T was established in November 2006 based on Nordic values and a common mission to serve the society through technological and scientific development and the education of high class engineers. The goal of the alliance is to utilize shared and complementary strengths and create synergy within education, research and innovation.

The N5T ambition is supported by the establishment of joint international masters' programmes, shared recognition of bachelor's degrees, mutual learning and peer evaluation activities, and network activities to stimulate collaboration in research and education

A number of joint projects have been launched to support the vision of N5T as an extended campus in PhD education through exchange of PhD researchers, specialized PhD courses and joint supervision. These activities are supported by the PhD course database and the N5T PhD Administrators Working Group.

http://www.nordicfivetech.org/

ANNEX 2

CESAER MEMBER INSTITUTIONS AND THEIR MEMBERSHIP TO OTHER ASSOCIATIONS – CLUSTER, EUROTECH UNIVERSITIES, IDEA LEAGUE, NORDIC FIVE TECH.

	CESAER	CLUSTER	EuroTech Universities	IDEA League	Nordic Five Tech
Austria	Technische Universität Wien				
Belgium	Universiteit Gent, Faculteit Ingenieurswetenschappen				
	KULeuven, Faculteit Ingenieurswetenschappen	CLUSTER			
	Université Catholique de Louvain, Ecole Polytechnique	CLUSTER			
Czech Republic	Brno University of Technology	CLUSTER			
	Czech Technical University in Prague				
Denmark	Aalborg University, Faculty of Engineering and Science				
	Technical University of Denmark		EuroTech Universities		Nordic Five Tech
Estonia	Tallinnn University of Technology				
Finland	Aalto University	CLUSTER			Nordic Five Tech
France	Ecole Centrale Paris				
	Institut National Polytechnique de Grenoble	CLUSTER			
	Institut National des Sciences Appliquées de Lyon				
	ParisTech				
	SUPELEC - Ecole Supérieure d'Electricité				
Germany	Rheinisch-Westfälische Technische Hochschule			IDEA League	
	Technische Universität Berlin				
	Technische Universität Carolo-Wilhelmina zu Braunschweig				
	Technische Universität Darmstadt	CLUSTER			
	Technische Universität Dresden				
	Technische Universität Hamburg-Harburg				
	Gottfried Wilhelm Leibniz Universität Hannover				
	Karlsruhe Institute of Technology				
	Technische Universität München		EuroTech Universities		

Greece	Aristotle University of Thessaloniki, School of Engineering				
Hungary	Budapest University of Technology and Economics				
Ireland *not in CESAER*	University College Dublin				
	Trinity College Dublin	CLUSTER			
Israel	Technion, Israel Institute of Technology				
Italy	Politecnico di Milano				
	Politecnico di Torino	CLUSTER			
Lithuania	Kaunas University of Technology				
Netherlands	Technische Universiteit Delft			IDEA League	
	Technische Universiteit Eindhoven	CLUSTER	EuroTech Universities		
	Universiteit Twente				
Norway	The Norwegian University of Science and Technology (NTNU)				Nordic Five Tech
Poland	Politechnika Poznanska				
	Warsaw University of Technology				
Portugal	Instituto Superior Técnico, Lisbon	CLUSTER			
	Universidade do Porto, Faculty of Engineering (FEUP)				
Romania	Universitatea Politehnica Bucuresti				
Russia	Tomsk Polytechnic University				
Spain	Universitat Politècnica de Catalunya	CLUSTER			
	Universidad Politécnica de Madrid				
	Universidad Politécnica de Valencia				
Sweden	Chalmers University of Technology			IDEA League	Nordic Five Tech
	Lund University, Faculty of Engineering LTH				
	The Royal Institute of Technology (KTH)	CLUSTER			Nordic Five Tech
Switzerland	Ecole Polytechnique Fédérale de Lausanne	CLUSTER	EuroTech Universities		
	Eidgenössische Technische Hochschule Zürich			IDEA League	
Turkey	Istanbul Technical University				

ANNEX 3

ADDITIONAL PRACTICAL EXAMPLES

1. INTERDISCIPLINARY RESEARCH OPTIONS

CEITEC Brno University of Technology Doctoral School
CEITEC Doctoral School is innovative, interdisciplinary, fast-growing, and internationally-oriented, founded upon the strategic partnership of leading universities and research institutes in the region that are part of the CEITEC research centre: Masaryk University, Brno University of Technology, Mendel University in Brno, University of Veterinary and Pharmaceutical Sciences in Brno, Veterinary Research Institute and the Institute of Physics of Materials of the Academy of Sciences of the Czech Republic. The joint Doctoral School offers access to state-of-the-art infrastructure and training in an interdisciplinary scientific community. The doctoral projects are aimed at interdisciplinary topics and, according to their content, they are destined to result in major scientific discoveries and applicability is also emphasized.
http://www.ceitec.eu/phd-school/t1741

Karlsruhe Institute of Technology: Institute of Technology Assessment and Systems Analysis
The Institute for Technology Assessment and Systems Analysis (ITAS) provides doctoral researchers with the opportunity to earn a doctorate in a multidisciplinary environment. The role of the Institute is to investigate scientific and technological developments with a focus on their impacts and possible systemic and unintended effects. It produces analytical knowledge and assessments of socio-technical developments in order to provide policy and design options for decision-makers. The research covers ethical, ecological, economic, social, political-institutional, and cultural questions. As a research institute within KIT, ITAS is also involved in teaching and focuses on courses and lectures on Technology Assessment and Science and Technology Studies (STS).
http://www.itas.kit.edu/english/teaching.php

OTHER INTERDISCIPLINARY DOCTORAL SCHOOLS INAUGURATED ACROSS EUROPE'S UNIVERSITIES OF SCIENCE AND TECHNOLOGY

Ecole Polytechnique Fédérale de Lausanne
Doctoral Programme in Photonics
http://phd.epfl.ch/EDPO

University of Twente
MESA+ Institute for Nanotechnology
http://www.utwente.nl/mesaplus/
CTIT, ICT Research in Context
http://www.utwente.nl/ctit/
MIRA Institute for Biomedical Technology and Technical Medicine
http://www.utwente.nl/mira/
IGS Institute for Innovation and Governance Studies
http://www.utwente.nl/igs/

Universitat Politècnica de València
Doctoral Programme Telecommunications
http://www.upv.es/entidades/EDOCTORADO/indexi.html

Vienna University of Technology
Cyber-Physical Production Systems
http://dc-cpps.tuwien.ac.at/

2. TRAINING IN TRANSFERABLE COMPETENCES, CAPABILITIES AND SKILLS

PhDs Enhanced for Prospects – ERASMUS+ Strategic Partnership

The PhDs Enhance for Prospects (PEP UP) project aims a developing strategic partnerships between eight European universities (Aalborg University, RWTH Aachen University, Trinity College Dublin, INSA Lyon, Politecnico di Torino, TU Delft, University of Porto, University of Loughborough), two companies (INFINEON, HILTI) and two regions (Région Rhone Alpes and Regione Piemonte) around a common issue: enhancing the value of doctoral researchers' professional skills in order to improve their employability in companies. The project's target population are doctoral researchers in engineering. It aims to create an opportunity for the industrial partners to communicate their needs, thus ensuring that doctoral training programmes make doctoral graduates more prepared for employment in industry and more able to use their talents and training for the benefit of the economy, regions and society. For the doctoral researchers, it aims at raising the awareness regarding the need for transferable competences, capabilities and skills and at co-developing a five-day module that will be delivered to selected doctoral researchers from participating institutions.
http://www.insa-lyon.fr/en/node/4906

EuroTech Universities and Nordic Five Tech: Promoting researcher mobility through joint databases of doctoral courses

In 2014, EuroTech Universities launched a joint database of doctoral courses, covering both technical and non-technical courses and open to all doctoral researchers registered in one of the EuroTech Universities. The joint database promotes international mobility and interdisciplinary research collaboration among the doctoral researchers. Furthermore, the joint database also results in more rational use of resources, including research infrastructures, between the four partner universities.
http://www.phdcourses.nordicfivetech.org/

The EuroTech Universities launched a similar database in 2013.
https://www.phdcourses.eurotech-universities.org/

Other programmes including transferable skills offered across Europe's universities of science and technology

TU Delft: Graduate School – Doctoral Education Programme
https://intranet.tudelft.nl/en/targeted-info/graduateschool/doctoral-education-programme/

Dresden University of Technology: Graduate Academy
http://tu-dresden.de/die_tu_dresden/zentrale_einrichtungen/graduiertenakademie

Eindhoven University of Technology: PROOF - Providing Opportunities for Doctoral Researchers
http://www.tue.nl/en/university/working-at-tue/development-and-career/scientific-personnel/phd-and-postdoc/

Leibniz Universitäten Hannover: Promotion plus+ - Career Prospects for doctoral researchers
http://www.graduiertenakademie.uni-hannover.de/promotion.html?&L=1

3. EXPOSURE TO INDUSTRY

Eindhoven University of Technology: Impuls Programme
Together with its partners in industry and research, TU/e (Eindhoven University of Technology) is co-funding 250 extra PhD researchers in 2014-2015 through the Impuls Programme. Through the Programme, TU/e is investing €23 million and is making available the required accommodation and facilities. Companies and fellow research institutes are investing a further € 30-40 million.

Through this initiative, TU/e and its partners aim to strengthen the research partnerships in important areas such as energy, health, mobility, high-tech systems, data science and materials - fields in which numerous companies and organizations in the Brainport region are working on innovative solutions
https://www.tue.nl/en/university/working-at-tue/tue-impuls/

Technical University of Denmark: Industrial Doctorate
DTU (Technical University of Denmark) collaborates with a vast number of businesses in educating of PhD doctoral researchers. The following applying two models of collaboration are available: **Co-funding a doctoral researcher:** Businesses who interested in having a specific problem investigated have the option of partially financing a doctoral researcher at DTU. Doctoral researchers enrolled in a research school typically receive funding from a business for one year. The funding covers salary, tuition fees and overhead to the university. **Industrial Doctorate:** This arrangement is administered by Innovation Fund Denmark. The purpose of the arrangement is to further development and innovation in the Danish business community. The Innovation Fund provides financial support to businesses that wish to take on industrial doctoral researchers.
http://www.dtu.dk/english/Education/phd#industrialphd

University of Porto, Faculty of Engineering (FEUP): Doctoral Programmes on Refining, Petrochemical and Chemical Engineering
The Doctoral programme emerged as a result of cooperation in Portugal between (i) the five major universities with education and research programmes in that area; (ii) five large companies in the sector; and (iii) the Petrochemical cluster set up in 2009 known as Petrochemical, Chemical and Refining Industry Association (AIPQR), through which also other companies may benefit from the programme.

The programme offers advanced training for doctoral candidates in an industrial setting or post-graduate training and individual modules in a lifelong learning perspective. The definition of research and development themes are provided by the companies involved, which is a great opportunity for increasing the competitiveness of this industrial cluster.

During the curricular activities, classes can be attended at three different locations spread across the country and specialists from industry regularly collaborate on the programme's curriculum..
http://www.phdportal.eu/studies/21050/doctoral-programme-in-refining-petrochemical-and-chemical-engineering.html

4. INTERNATIONAL NETWORKING

Joint international doctoral programme at Danish Technical University (DTU)
The programme is a joint initiative between DTU together with the Norwegian University of Science and Technology National university of Singapore. The doctoral programme consists of an independent scientific project, a study programme corresponding to 30 ECTS, teaching and dissemination activities corresponding to approximately 3 months, a doctoral thesis, and a public defense. A stay and research work at an external partner university is an integrated part of the programme. Persons who complete the PhD programme at DTU will encompass knowledge, skills, and competences.
http://www-dtu.dk/phd

Ecole Polytechnique Fédérale de Lausanne: International Recruitment at the doctoral school
About 80% of the EPFL doctoral researchers are first educated outside Switzerland. A variety of services make the transition for these researchers as smooth as possible. Each PhD candidate is for example assigned a mentor who can help in case there are communication or other difficulties (possibly related to differences in cultural backgrounds) with the supervision of the candidate or the candidate's integration.

International summer schools are also offered as tool to stimulate exchanges with foreign universities. EPFL doctoral researchers have to possibility to initiate their own international summer school (the content of the scientific program is validated by the doctoral programme committee). The participation of doctoral researchers from foreign universities is stimulated by financing their participation (travel and accommodation costs).
http://phd.epfl.ch/page-19488-en.html

Technische Universität Wien: International Doctoral College - Spatial Research Lab
Doctoral researchers are required to embark on independent explorations of uncharted academic territory within the framework of their individual doctoral theses. The Doctoral College involves partner universities from Austria, Germany and Switzerland, Germany and takes difficult, highly complex and complicated problems of spatial development as its starting point. The latter usually cut across several different disciplines, affect a diverse range of geographical reference areas and involve numerous actors from the public and private sectors. The doctoral researchers at the participating universities analyze significant spatial issues relating to the transformation of cities and landscapes of national and European importance. The objective is to explore the possibilities of cross-border concepts and strategies, test suitable tools and approaches and demonstrate the effects and consequences of spatially relevant actions and decisions by means of experimental simulations.
http://www.forschungslabor-raum.info

REFERENCES

(Endnotes)

[1] Alan I. Leshner: Rethinking graduate education. Editorial. 24 July 2015, SCIENCE Vol. 349, Issue 6248, p. 349

[2] Avid Cyranoski et al.: The PhD Factory: The world is producing more PhDs than ever before. Is it time to stop? NATURE Vol. 472, pp. 276-279, 21 April 2015

[3] Hans-Ulrich Heiss: Die Ingenieurpromotion. 06 June 2015: http://www.forschung-und-lehre.de/wordpress/?p=18874&print=1

[4] European Commission: Principles for Innovative Doctoral Training. Brussels, 27 June 2011

[5] European Commission: Exploration of the implementation of the Principles for Innovative Doctoral Training in Europe, 2011

[6] European Commission: Exploration of the implementation of the Principles for Innovative Doctoral Training in Europe, 2011

[7] See e.g. Erich Jantsch: Towards interdisciplinarity and transdisciplinarity in education and innovation. In: Interdisciplinarity. Problems of teaching and research in universities. Centre for educational research and innovation. OECD, Paris, 1972. pp. 97 ff.

[8] "The University and the Community. The Problems of Changing Relationships". OECD Centre for Educational Research and Innovation. Paris 1982, p. 127

[9] The Lund declaration: Europe must focus on the grand challenges of our time. July 2009. See: http://cordis.europa.eu/news/rcn/31013_en.html

[10] Alvin M. Weinberg: But is the teacher also a citizen? SCIENCE, Vol. 149, 6 August 1965, p. 601

[11] Manfred Horvat: Continuing Engineering Education as a Driving Force in University Development. In: Pia Lappaleinen (Ed.): European Engineering Education. Conceptualizing the Lessons Learned. SEFI and TKK Dipoli, 2009. pp. 17 ff.

[12] VDI (Society of German Engineers): Technology Assessment. Concepts and Foundations. VDI 3780. 1991

[13] Jeroen van den Hoven: Value Sensitive Design and Responsible Innovation. In: Richard Owen, John Besant and Maggy Heintz (Eds.): Responsible Innovation. Managing the Responsible Emergence of Science and Innovation in Society. John Wiley & Sons Ltd., 2013. p. 78

[14] “Research Careers in European Landscape and Horizons”, European Science Foundation 2010, Cited following: European Commission: Principles of Innovative Doctoral Training, Brussels, 27 June 2011

[15] OECD: Transferable Skills Training for Researchers – Supporting career development and research. OECD, Paris, 2012, p. 20

[16] See also e.g.: Allen F. Repko: Interdisciplinary research. Process and Theory. SAGE, 2012, pp. 58 ff.

[17] OECD: Transferable Skills Training for Researchers – Supporting career development and research. OECD, Paris, 2012, p. 15

[18] Dorothy Leonard: Wellsprings of Knowledge: Building and Sustaining the Sources of Innovation, Harvard Business School Press, 1995, pp. 75-77

[19] See: http://ec.europa.eu/programmes/horizon2020/en/h2020-section/responsible-research-innovation, and Richard Owen: Responsible Research and Innovation – Options for Research and Innovation Policy in the EU. ERIAB Policy Brief; Jeroen van den Hoven: Options for Strengthening Expert Report to the European Commission, 2013; Rome Declaration on Responsible Research and Innovation in Europe, 2014 Italian Presidency of the Council of the European Union, 21 November 2014

[20] See the EuroTech Universities Alliance position paper “Nurturing the entrepreneurs of tomorrow – a central role for Europe’s Universities”, 29 June 2015: http://eurotech-universities.eu/nurturing-the-entrepreneurs-of-tomorrow-a-contribution-of-the-eurotech-universities-alliance-eurotech-universities-policy-paper/ and the Executive Summary of the 2013 CESAER Seminar: „Educating and training the next generation of technology entrepreneurs“ at RWTH Aachen University: http://www.cesaer.org/en/publications/

[21] See e.g.: The Royal Society: Knowledge, Networks and Nations. Global Scientific Cooperation in the 21st Century. London, March 2013

[22] Op.cit. p.46

[23] Op.cit.p.48

[24] S. Milojevic, Principles of scientific research team formation. PNAS, March 18, 2014, Vol.11, no.11, pp.3984-3989

[25] J. Kamalski and A. Plume: Comparative Benchmarking of European and US research Collaboration and Researcher Mobility - A report prepared in collaboration between Science Europe and Elsevier’s SciVal Analytics (September 2013)

[26] http://www.igsse.tum.de/

NOTES

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