



> Recommendations on the Future of the Engineering Doctorate

Strategies for the further improvement
and strengthening of the engineering doctorate
at German universities

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Munich Office
Residenz München
Hofgartenstrasse 2
80539 München

Berlin Office
Unter den Linden 14
10117 Berlin

Brussels Office
Rue du Commerce/
Handelsstraat 31
1000 Brüssel

T +49 (0)89/5203090
F +49 (0)89/5203099

T +49 (0)30/206309610
F +49 (0)30/206309611

T +32 (0)/25046060
F +32 (0)25046069

E-mail: info@acatech.de
Website: www.acatech.de

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Coordination: Dr. Martina Röbbcke, Dr. Mandy Pastohr
Edited by: Dr. Martina Röbbcke
Translation: HIGH-TECH Hay GmbH; Übersetzungen, München
Layout concept: acatech
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INTRODUCTORY REMARKS ON THIS SUMMARY

Between the start of 2007 and summer 2008, a project group led by Prof. Dr.-Ing. Michael Zäh worked with the head of the acatech network "Education and Knowledge" Prof. Dr.-Ing. Günter Pritschow and a number of other contributors to prepare the project report "Empfehlungen zur Zukunft der Ingenieurpromotion".

This project report was syndicated via the acatech executive board in September 2008 prior to its subsequent publication and presentation to the public as part of the acatech forum "Zukunft der Ingenieurpromotion" held on 19 Sep-

tember 2008. The report (in German) contains the full results of the project and is available from acatech - National Academy of Science and Engineering.

Due to the high level of interest in the German engineering doctorate and ongoing discussions on the structure of engineering doctorates in Europe, acatech commissioned a translation of the report. This publication is an updated and translated summary of the project report.

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> PROJECT

> PROJECT MANAGEMENT

- Prof. Dr.-Ing. Michael F. Zäh, Technische Universität München/acatech

> HEAD OF THE acatech NETWORK “EDUCATION AND KNOWLEDGE”

- Prof. Dr.-Ing. Dr. h.c. mult. Dr.-Ing. E.h. Günter Pritschow, Universität Stuttgart/acatech

> PROJECT GROUP

- Prof. Dr.-Ing. habil. Ekkard Brinksmeier, Universität Bremen/acatech
- Prof. Dr.-Ing. Dr.-Ing. E.h. Heinz Duddeck, Technische Universität Braunschweig/acatech
- Prof. Dr.-Ing. habil. Horst Goldhahn, Technische Universität Dresden/acatech
- Prof. Dr.-Ing. Dr.-Ing. E.h. Joachim Heinzl, Technische Universität München/acatech
- Prof. Dr. sc. tech. Horst Hippler, Karlsruhe Institut für Technologie/TU9
- Prof. Dr.-Ing. Bernd-Robert Höhn, Technische Universität München/acatech
- Prof. Dr.-Ing. rer. nat. Michael Hoffmann, Universität Ulm/4ING
- Prof. Dr.-Ing. habil. Helmut Kipphan, Heidelberger Druckmaschinen AG/acatech
- Prof. Dr.-Ing. Dr. h.c. mult. Dr.-Ing. E.h. Reiner Kopp, RWTH Aachen/acatech
- Prof. Dr.-Ing. Eckart Kottkamp, Verband Deutscher Maschinen- und Anlagenbau e. V. (VDMA); Hako Holding GmbH & Co.
- Prof. Dr.-Ing. habil. Dr. h.c. Werner Krause, Technische Universität Dresden/acatech

- Prof. Dr.-Ing. Dr. h.c. mult. Paul J. Kühn, Universität Stuttgart/acatech
- Prof. Dr.-Ing. Manfred Nagl, RWTH Aachen/4ING
- Prof. Dr.-Ing. Peter Pirsch, Universität Hannover/Verein Deutscher Ingenieure (VDI)
- Prof. Dr.-Ing. Gunther Reinhart, Technische Universität München/acatech
- Prof. Dr.-Ing. habil. Rolf Thiele, Universität Leipzig/acatech
- Prof. Dr.-Ing. habil. Petra Winzer, Bergische Universität Wuppertal/acatech
- Prof. Dr.-Ing. Dr.-Ing. E.h. Eugen-Georg Woschni, Technische Universität Chemnitz/acatech

> OTHER CONTRIBUTORS

The following individuals contributed to the success of the project through their participation in meetings and workshops. This does not automatically infer that they fully support all of the recommendations detailed here. The personal opinion of one or more of these individuals may differ from the statements and recommendations contained in this text. Their participation and input is very much appreciated.

- Prof. Dr. ir. Hendrik van Brussel, Katholieke Universiteit Leuven, Belgium
- Prof. Dr.-Ing. Gerry Byrne, University College Dublin, Ireland
- Prof. Didier Dumur (Ph.D.), École Supérieure d’Électricité, France
- Carola Feller, Verband Deutscher Maschinen- und Anlagenbau e.V. (VDMA)
- Prof. Livan Frattini (Ph.D.), Università degli Studi di Palermo, Italy
- Dr. Christiane Gaehtgens, Hochschulrektorenkonferenz (HRK)

- Ministerialdirigent Peter Greisler, Bundesministerium für Bildung und Forschung (BMBF)
- Ministerialdirigent Dr. Birger Hendriks, Ministerium für Wissenschaft, Wirtschaft und Verkehr des Landes Schleswig-Holstein; Kultusministerkonferenz (KMK)
- Prof. Dr. Susanne Ihsen, Technische Universität München
- Bettina Jorzik, Stifterverband für die Deutsche Wissenschaft
- Dr.-Ing. Michael Klimke, Technische Universität München
- Prof. Dr.-Ing. Dr. h. c. Dieter Mewes, Universität Hannover
- Prof. Giovanni Perrone (Ph.D.), Università degli Studi di Palermo, Italy
- Prof. Dr. Ernst Rank, Technische Universität München
- Hartmut Rauen, Verband Deutscher Maschinen- und Anlagenbau e.V. (VDMA)
- Dr.-Ing. Wolfgang Staguhn, Daimler AG
- Prof. Dr.-Ing. Dietmar Theis, Siemens AG
- Manfred Wittenstein, Verband Deutscher Maschinen- und Anlagenbau e.V. (VDMA); Wittenstein AG

> COMMISSIONS

As part of this project, the Center for Higher Education Policy Studies (CHEPS) at the University of Twente in the Netherlands was commissioned to conduct surveys and compile reports on engineering doctorates in selected countries. Many thanks to Prof. Dr. Jürgen Enders, Director of CHEPS, and his team for their commitment and cooperation.

> PROJECT COORDINATION

- Dr. Martina Röbbcke, acatech (Berlin office)
- Dr. Jens Pape, acatech (Munich office)
- Dr.-Ing. Jochen Holzkamp, Hamburg
- Andreas Trautmann, M.Sc., Technische Universität München

PREAMBLE

The overall picture of the process and outcomes of the engineering doctorate¹ in Germany is very satisfactory. Universities² train highly-skilled academic professionals in the engineering disciplines, while male and female doctoral degree holders alike³ enjoy an excellent professional reputation in scientific and business circles both nationally and internationally. Engineering doctorates at German universities have a strong focus on largely independent research, teaching and project work⁴, thus ensuring doctoral students develop a comprehensive range of skills and distinguishing German engineering from its international counterparts.

Doctoral students play a particularly important role in the interaction between business and science in Germany. They are the main conduit for project-based cooperation between universities and industry. Among other things, this facilitates the transfer of core knowledge and technology essential in the development of new innovations. Former doctoral students now working in the industrial sector are also a key element both in this fruitful interaction and in building networks between business and science. They in-

ject their professional experience back into the university environment and, in return, gain important stimuli for their careers as researchers and managers.

Despite this, the Bologna Process opens up new opportunities which need to be evaluated. This requires a critical examination of the structure, general conditions and results of the doctoral phase of engineering studies at German universities, and identification of potential for improvement.

The strategies drawn up by acatech for improving and consolidating the engineering doctorate are designed to help maintain and reinforce the high quality of this qualification in Germany. Furthermore, they are intended to safeguard the current high level of interest in doctoral courses in the future and to ensure that doctoral degree holders continue to be a driving force in improving research and technology in the scientific and business sectors. This will build the foundations needed to create innovative products that will prove competitive on the international market.

¹ Here, and in the remainder of the text, this refers to doctorates in engineering (civil engineering, electrical engineering/information technology and mechanical engineering/process engineering) and computer science. For the purposes of this paper, "engineering" should be understood as an umbrella term also covering all the sub-areas of computer science that define themselves as part of the engineering disciplines.

² Here, and in the remainder of the text, this refers to all universities and technical universities offering engineering courses.

³ The text does not distinguish between genders. Any masculine forms used in reference to engineers (he, his, etc.) are assumed to refer to both men and women.

⁴ Project work refers to research projects carried out for public bodies or the industrial sector over a limited period of time, either individually or in collaboration with others.

1 INTRODUCTION

Over the past few years, the Bologna Process has brought considerable changes to higher education in Germany. In 1999, a total of 29 European nations committed themselves to the establishment of a common European Higher Education Area by 2010. The most striking feature of the Bologna reforms is the shift to a two-cycle Bachelor/Master degree system.

In 2006, acatech made recommendations for the introduction of Bachelor's and Master's degrees in engineering.⁵ These outlined the consequences of the Bologna Process for the disciplines of mechanical engineering/process engineering, electrical engineering/information technology/computer science and civil engineering. The recommendations also included proposals for revising the content of these courses, including a critical assessment of the courses on offer, their currency and relevance and, if necessary, a shift in direction due to the changing requirements of the business and scientific sectors.

The targets set in Bologna in 1999 did not remain limited to the introduction of a two-cycle system of study. At a meeting in Berlin in 2003, Europe's education ministers extended these targets by naming doctoral training as the third "cycle" of the Bologna Process, further to the Bachelor's and Master's courses. As established in the Bergen Communiqué of 2005⁶, this third cycle generally corresponds to a three- to four-year period of full-time study. Doctoral candidates are regarded both as students and as academic professionals. In the Communiqué, the ministers in charge of higher education also called on universities to do more to promote interdisciplinary training and the development of professional skills during the doctoral phase. They also identified a need for structured doctoral degree courses and a transparent system of supervision and assessment.

The very general conclusions contained in the Bergen Communiqué were preceded by more concrete discussions by the European University Association (EUA)⁷ in February 2005. This resulted in seven principles designed to underpin further discussion of the doctoral phase. The core elements are recognition of the doctorate as a phase of employment, a variety of doctoral models, the key importance of supervision, an average duration of three to four years and improved mobility. The desirability of maintaining diversity in doctoral training is further underlined by the London Communiqué of 2007.⁸

The doctoral phase also faces challenges arising from changes to the underlying conditions governing science and the teaching and research process. The following developments have been observed in the recent years:

- Increase in knowledge: Scientific information and human knowledge continue to grow exponentially.
- Specialisation: The growth in human knowledge is leading to specialisation processes.
- Differentiation: New areas of study are emerging on the fringes of the traditional disciplines.
- Interdisciplinary work: These three changes in the conditions governing science are altering research and development in a disciplinary context. The growing complexity of scientific studies often demands an inter- or multidisciplinary approach that – depending on scope, organisational framework and resources – can often only be realised through collaboration between a number of researchers or scientific working groups.
- Internationalisation: Science is increasingly geared towards international cooperation. At the same time, it also has to hold its own against international competition.

⁵ Cf. acatech 2006.

⁶ Cf. Bergen 2005.

⁷ Cf. EUA 2005.

⁸ Cf. London 2007.

Academic professionals are expected to have a broad range of skills and abilities. They are required to demonstrate a non-academic approach to addressing and defining problems, a project-oriented approach to research and the ability to determine the quality thereof. Furthermore, interdisciplinary research relies on new supervision structures and parallel paths for imparting additional knowledge.

In view of all these factors, it is hardly surprising that reforms to doctoral training have long been one of the core issues on the scientific agenda in Germany and throughout Europe.

1.1 THE TYPICAL GERMAN MODEL – THE RESEARCH ASSISTANT PATH

The engineering doctorate has a long and extremely successful tradition in Germany. The country's universities can look back on over a century of training academic professionals in the fields of science and engineering. The granting of the right to award doctoral degrees at the turn of the 19th century also marked the conclusion of many years of effort by the "Technikerbewegung" (engineers' movement). This movement aimed to secure proper recognition of the new "technical sciences", achieve parity between the new technology-oriented institutions of higher education and the established universities, and gain social acceptance for a new profession – that of the engineer.⁹

A typical engineering doctorate in Germany requires the candidate to spend a specified period of time working as a research assistant, funded either by the state or by a third party.¹⁰ This model – often referred to in German as the "Meister-Schüler-Modell" (master-apprentice model) or "As-

sistenz-Promotion" (research assistant path) – is characterised as follows:¹¹

- The doctorate is – under the guidance of a supervising member of the university teaching staff – regarded as a first stage in independent research and employment and as preparation for a management function.
- The doctorate focuses primarily on developing new scientific findings and presenting these in the form of a thesis.
- With the doctorate serving as a first step on the career path, the candidate – in addition to completing a piece of original scientific research – also acquires a range of other skills and abilities. This is done by participating in teaching activities, acquiring and organising research projects, taking part in ongoing activities within the relevant department/institute, managing his own doctoral project, discussing and presenting general teaching content in addition to his own research results, managing staff and interdisciplinary cooperation.

In Germany, this model is deemed extremely successful by the scientific and business sectors alike:

- German universities provide excellent training, giving engineering students internationally recognised skills both within and outside their specific field. In its current form, the engineering doctorate regularly enables graduates to successfully acquire responsible positions in the business sector.
- The work that research assistants do during the doctoral phase is crucial to university teaching and to project-based (research) collaborations between companies and universities. The role of the doctoral student provides an outstanding basis for "person-to-person" technology transfer, which is far superior to formalised cooperation

⁹ Cf. König 1999.

¹⁰ Nearly 90 % of all engineering doctorates in Germany follow the research assistant path, while a further 10 % are completed in research training groups. acatech has no figures for doctorates completed externally, i.e. in the industrial sector, but these are likely to be under 10 %.

¹¹ See also 4ING 2006 and/or TU9 2007.

models. Both science and business derive benefits from this system, which – particularly in respect to the close collaboration between companies and universities – is fundamentally different to systems in other countries. It forms an excellent foundation for research in the field of engineering that is both practice-oriented and scientifically sound.

This model has achieved widespread renown both in Germany and abroad. However, the engineering doctorate is now being viewed more critically as part of recent discussions on ways to improve the doctoral phase.

Enders/Bornmann¹² identify a range of weaknesses evident in doctorates in all disciplines, i.e. also in engineering. These include:

- the lack of transparency in the selection process,
- the long duration of the doctorate (often over five to six years),
- the often unsystematic training which is highly dependent on the supervisor's commitment and input,
- the lack of non-subject-specific or soft skills,
- the students' high dependency on their designated supervisor.

In addition to discussing a number of familiar issues, a study carried out by the German Engineering Federation (Verband Deutscher Maschinen- und Anlagenbau e.V., VDMA) on the current situation and the future of the engineering doctorate in Germany's universities¹³ also revealed that some potential for improvement still remains untapped. Many of the company representatives questioned by the VDMA called for improved qualifications in the fields of project management, leadership skills, management methods and

international skills, for example. For their part, doctoral students assumed that they would acquire most of these skills during their time as research assistants. The VDMA study concluded that these non-subject-specific skills were not yet at the level required by industry.

In addition to companies and doctoral students, the VDMA also asked doctoral degree holders now working in the industrial sector about their experiences during their own doctorates. They called for improved organisation, planning and supervision, and criticised the lack of regular meetings with supervisors to receive feedback and agree how the research should progress. The doctoral degree holders were also keen to see less bureaucracy, fewer activities not directly related to the doctorate and greater transparency in terms of financing and facilities. The study also revealed that there was often little clarification of key milestones in the process.

1.2 NEW DOCTORAL MODELS – NEW APPROACHES

Reforms to doctorates at German universities have been put on the agenda not only due to the weaknesses described above, but also in an effort to improve the international competitiveness of the German research system. Scientific and higher education bodies such as the German Council of Science and Humanities (Wissenschaftsrat)¹⁴ and the German Rectors' Conference (Hochschulrektorenkonferenz, HRK)¹⁵ generally support structured models for doctoral training.¹⁶

The research training groups organised by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) are pioneering in this field. Research training groups are designed to complement, not replace, traditional

¹² Cf. Enders/Bornmann 2001.

¹³ Cf. VDMA 2006.

¹⁴ Cf. German Council of Science and Humanities 2002.

¹⁵ Cf. HRK 2003.

¹⁶ Here, and in the remainder of the text, the term "structured models" is used as a terminus technicus, although other approaches to the doctorate may set this as an objective.

one-on-one supervision. The groups give doctoral students an opportunity to work on their doctorate as part of a co-ordinated research programme supported by a number of tutors. In addition to support from designated supervisors, the students are also integrated into research projects conducted by the various bodies involved in the group. Furthermore, a training programme provides a comprehensive introduction to and broader understanding of the specific branch of science in which the work is performed.¹⁷

The first DFG research training group was set up as early as 1990. The groups are entitled to support for a maximum of 9 years. In 2009, the DFG funded a total of 258 research training groups, including 39 in engineering and computer science.¹⁸ According to the DFG, around 10 % of all engineering doctorates in Germany are completed as part of a research training group.

Based on the model of research groups, a series of graduate schools have since been developed. In contrast to the research training groups, graduate schools in Germany are long-term organisational units (as opposed to “schools” in the traditional sense of the word) encompassing a wide range of subjects and, in many cases, a number of different doctoral courses. Although these courses differ as regards the type of financing and the degree to which they have a set curriculum, they are generally strongly oriented towards the reforms proposed by the German Council of Science and Humanities and the German Rectors’ Conference. Consequently, they focus on shortening the duration of the doctorate, supporting particularly gifted graduates and providing key additional (non-specialist) skills. Examples of structured doctoral models include:

- International Doctoral Programmes (IPP) run by the German Academic Exchange Service (Deutscher Akademischer Austausch Dienst, DAAD) and the DFG. In addition to non-subject-specific topics, the courses held as part of these internationally-oriented doctoral programmes also teach methods and presentation skills.¹⁹
- International Max Planck Research Schools (IMPRS) run by the Max Planck Society (Max-Planck-Gesellschaft). The Max Planck Society founded the first International Max Planck Research Schools (IMPRS) in 2000 in consultation with the German Rectors’ Conference. The schools enjoy close links with universities, have a strong international focus and concentrate on interdisciplinary research topics.²⁰
- Helmholtz Research Schools and Graduate Schools organised by the Helmholtz Association of German Research Centres (Helmholtz-Gemeinschaft Deutscher Forschungszentren). The Helmholtz Association began establishing research schools and graduate schools in conjunction with universities in 2006.²¹
- Leibniz Graduate Schools run by the Leibniz Association (Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz, WGL). The WGL has been offering structured doctoral programmes in its now 18 Leibniz Graduate Schools since 2006.²²
- Doctoral training groups run by organisations for the promotion of young talent (Begabtenförderungswerke). Some of these organisations have recently set up doctoral training groups in cooperation with universities. This framework is used to coordinate and align doctoral projects that share common themes.²³

¹⁷ Cf. www.dfg.de.

¹⁸ Cf. DFG 2011. In the period from 1999 to 2009, engineering and computer science accounted for between 11 and 15 % of the approved and/or funded research training groups.

¹⁹ Cf. www.daad.de and www.dfg.de.

²⁰ Cf. www.mpg.de/en/imprs.

²¹ Cf. www.helmholtz.de/jobs_talente/doktoranden/.

²² Cf. www.leibniz-gemeinschaft.de.

²³ Cf. www.begabtenfoerderungswerke.de.

- Graduate schools as part of the Initiative for Excellence (Exzellenzinitiative).

The DFG has been supporting graduate schools for doctoral students since 2006. These schools provide excellent research environments for the promotion of the next generation of exceptional academic professionals and are part of the Initiative for Excellence set up by Germany's federal and state governments to promote outstanding research at the country's universities. The following graduate schools have been established for engineering disciplines:²⁴

- Aachen Institute for Advanced Studies in Computational Engineering Science (AICES), Aachen,
- Graduate School of Computational Engineering, Darmstadt,
- Erlangen Graduate School in Advanced Optical Technologies, Erlangen,
- Graduate School for Computing in Medicine and Life Sciences, Lübeck,
- International Graduate School of Science and Engineering (IGSSE), Munich,
- Saarbrücken Graduate School of Computer Science, Saarbrücken,
- Graduate School for Advanced Manufacturing Engineering, Stuttgart.

There are also limited opportunities available for undertaking a doctorate in the specialist research areas of the German Research Foundation (DFG).

In addition to the programmes listed, certain universities and faculties have in recent years also developed their own range of doctoral courses, including for engineering.

The doctoral models mentioned here share several common features:²⁵

- Funding is generally limited to a period of three years,
- A study programme run in parallel to the doctorate (and organised in some cases on a curricular basis) provides structured training,
- Availability of courses to develop key skills,
- More formalised supervisory structures.

These programmes also share an international focus – albeit in differing levels of intensity – and this is reflected in the high proportion of foreign doctoral students, an English-language teaching programme and cooperation with scientists and institutions from outside Germany.

Some of these structured doctoral courses are specifically designed for the most talented graduates. A competitive, transparent selection process is supposed to ensure the best candidates are chosen.

²⁴ Cf. www.bmbf.de/1321.php.

²⁵ Cf. Berning/Falk 2006.

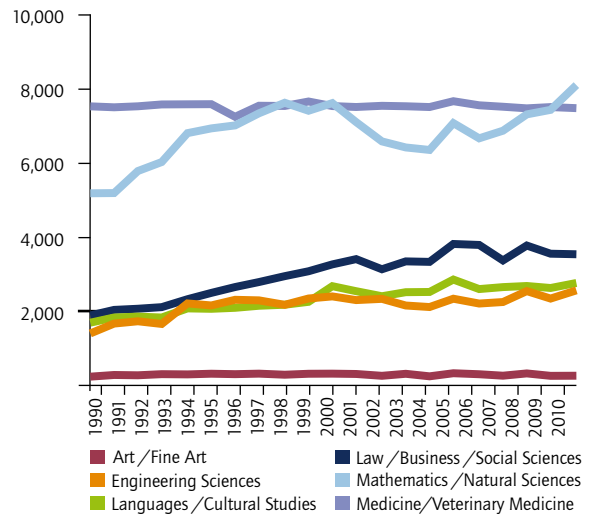
1.3 FACTS AND FIGURES ON THE GERMAN ENGINEERING DOCTORATE

The following examines how the number of engineering doctorates has developed over time. The figure shows the absolute figures for doctorates in Germany per subject group. A growth in the number of completed doctorates is evident in almost all the groups, including engineering. In the period since 1994, over 2,000 doctorates have been completed in this field every year.

As the table below shows, the number of female students completing doctorates has multiplied since 1990 (from 52 in 1990 to 394 in 2010), but women still only account for around 15 % of all engineering doctorates.

Demand on the labour market for doctoral degree holders goes hand in hand with the rise in the number of doctorates. There are no indications of any unusual shortfall in the number of doctoral degree holders in the engineering sector, nor is there any evidence of any lack of graduates in engineering as a whole.

Figure 1: Number of doctorates completed annually per subject group



Source: Federal Statistics Office 2007 and 2011a

The strategies drawn up by acatech for improving and consolidating the engineering doctorate are designed to safeguard the current high level of interest in doctoral courses

Engineering doctorates (1990–2010)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Total	1,400	1,666	1,728	1,656	2,209	2,155	2,307	2,292	2,172	2,342	2,398
Number of doctorates completed by women	52	77	75	97	153	144	163	191	180	181	246

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Total	2,299	2,332	2,153	2,112	2,336	2,206	2,247	2,541	2,340	2,561
Number of doctorates completed by women	262	232	225	238	317	299	278	363	400	394

Source: Federal Statistics Office 2007 and 2011a

in the future and to ensure that doctoral degree holders continue to be a driving force in pushing the boundaries of research and technology in the scientific and business sectors. This will build the foundations needed to create innovative products that will prove competitive on the international market.

1.4 POSITION STATEMENTS

Various faculties (4ING), associations representing technical universities (TU9), industry organisations (VDMA) and professional bodies such as the association of German engineers (VDI) are united in their support for those engineering doctorates where the candidate is employed as a research assistant attached to a particular department. Scientific policy organisations such as the German Council of Science and Humanities and the German Research Foundation underline the special role of the research assistant path in engineering doctorates. All the various bodies agree that further development of the doctoral phase is necessary to further improve and safeguard the quality of the skills acquired and the related scientific expertise.

Selected position statements on the engineering doctorate are summarised below:

German Engineering Federation (Verband Deutscher Maschinen- und Anlagenbau, VDMA)

A study conducted by the VDMA asked companies, doctoral students and doctoral degree holders now employed in the industrial sector to share their experiences of the engineering doctorate.²⁶ 85 % of companies are satisfied or very satisfied with the training and performance displayed by the doctoral degree holders in their employment. Identifying a key quality benchmark of the doctorate, they cite the diverse research collaborations between universities and

industry that ensure doctoral students gain experience of practice-oriented research topics at an early stage. 68 % of companies say the research skills gained during this period are extremely important to them. 85 % of doctoral degree holders with industrial experience also consider the doctorate has been an important factor in their success. Despite this largely positive feedback, they also feel aspects of the doctoral phase are in need of review. Although engineers occupy around two thirds of upper management positions, the companies do not feel the specific skills required for these roles are strongly developed among doctoral degree holders. The respondents identify shortcomings in a number of fields, including project management and awareness of corporate structures and management methods.

In its position paper, the VDMA therefore proposes intensifying the focus on developing skills and abilities in this area. As the study shows, resources for HR management and development could be used for this purpose. For their part, doctoral students say they receive inadequate subject-specific and personal feedback, barely any elements of target agreements are used and professional project management strategies are applied only rarely. As far as the VDMA is concerned, participation in a doctoral programme could be a useful addition to the system, but should in no way replace the established model where candidates work as research assistants.

The VDMA also proposes that, on average, doctorates should last no more than four years. However, the companies and doctoral students surveyed by the VDMA had different perceptions of the optimum period required for a doctorate. 61 % of companies supported a period of less than three years, while 33 % considered three to four years was appropriate. The doctoral students felt the ideal period would be somewhat longer, with 46 % citing three to four years and 42 % four to five years.

²⁶ Cf. VDMA 2006.

The VDMA also stated that the German doctor's degree title "Doktor-Ingenieur" or "Dr. Ing." – which is already established in business and university circles internationally – should be retained.

Umbrella Organisation of the German Faculties of Engineering and Informatics at Universities (4ING)²⁷

In September 2006, 4ING concluded a position paper on the engineering doctorate,²⁸ backed by numerous engineering associations and groups.²⁹ 4ING is in favour of retaining and developing the current model of the engineering doctorate, stating that Germany's research assistant path is recognised worldwide and should not be made more regulated. In addition to playing a key role in research, doctoral students contribute to their respective institutes by acquiring external funding, managing projects and so on. This also trains them in presentation and team leadership skills. As detailed in the paper, these soft skills are important on the labour market and much in demand on the international stage. 4ING opposes the introduction of strongly formalised doctoral courses as part of the internationalisation of academic degrees. The doctoral phase is viewed primarily as professional employment rather than an education/training phase.

4ING, TU9, acatech, et al.³⁰ issued a further statement on doctorates in engineering and natural sciences in 2009.

This calls for high quality standards in doctoral courses and for a range of different doctoral models in the European Higher Education Area.

4ING also firmly rejects the division of the doctoral phase (third cycle) into a scientific Ph.D. and an engineering doctorate.³¹ Furthermore, it opposes the concept of a "professional doctorate" in which the doctorate is awarded based on practical experience in the professional environment without submission of a thesis.³²

Network of Nine Technical Universities in Germany (TU9)³³

TU9 views the attainment of an engineering doctorate as the result of independent research generally undertaken within the framework of a research assistant post in a relevant research institute. A high level of competence and engineering expertise is achieved primarily through "learning by doing". This would be lost if the engineering doctorate were to be given a curriculum similar to that of a study programme.³⁴ For that reason, TU9 approves the development of structured doctoral training on the one hand and a range of different paths on the other, but opposes increased regulation of the doctoral phase.³⁵

Speedy completion of the doctorate is a key objective for the members of TU9. To that end, the time required to complete a doctorate, including all additional academic

²⁷ 4ING is the umbrella organisation of the German faculties of engineering and informatics at universities (Fakultätentage der Ingenieurwissenschaften und der Informatik an Universitäten). It represents over 127 faculties and departments at universities and technical universities in the German-speaking region. These account for over 90 % of university courses and research in civil engineering, geodesy, mechanical engineering, process engineering, electrical engineering, information technology and computer science.

²⁸ Cf. 4ING 2006.

²⁹ Zentralverband Elektrotechnik- und Elektronikindustrie e.V. (ZVEI), Bundesingenieurkammer, Verband Deutscher Maschinen- und Anlagenbau e.V. (VDMA), Verband der Elektrotechnik, Elektronik und Informationstechnik e.V. (VDE), Hauptverband der Deutschen Bauindustrie, AMA Fachverband für Sensorik e.V., Gesellschaft für Informatik e.V. (GI), VGB PowerTech e.V., Gesellschaft für Chemische Technik und Biotechnologie e.V. (DECHEMA). acatech also supported the paper.

³⁰ Cf. acatech, TU9, 4ING et al. 2009.

³¹ Cf. 4ING 2011.

³² Cf. 4ING 2007.

³³ TU9 is an association representing the nine leading technical universities in Germany: RWTH Aachen, TU Berlin, TU Braunschweig, TU Darmstadt, TU Dresden, Universität Hannover, Karlsruhe Institute of Technology, TU München, Universität Stuttgart.

³⁴ Cf. TU9 2007.

³⁵ Cf. *ibid.* and acatech, TU9, 4ING et al. 2009.

activities, should not exceed five years. The research content should be such that it can be completed within three man-years.³⁶

Conference of European Schools of Advanced Engineering Education and Research (CESAER)³⁷

European organisation CESAER has also joined the debate on the engineering doctorate.³⁸ According to CESAER, the doctorate does not represent a third phase of study, but a first step towards independent research activity and a preparation for a scientific career and employment in industry. As individual research is the core element of a doctoral course, CESAER does not view a strict curriculum as beneficial to the completion of a doctorate. Rapid completion of the doctorate is a key objective and demands optimal framework conditions in terms of supervision and facilities. This would generally require a period of three to five years.

Association of German Engineers (Verein Deutscher Ingenieure, VDI)

The Association of German Engineers underlines that the German research assistant path will remain the normal national model for doctorates in the engineering disciplines in the future.³⁹ It is assumed that any further developments will include a more defined structure for the doctoral phase. This structure should ensure the non-research elements of the doctoral phase are firmly embedded in the process and limit the overall duration to around four years. Non-subject-specific activities are deemed particularly important. At project and institute level, these activities should be complemented by certain non-subject-specific courses offered by the respective faculty. In future, the engineering doctorate should, on the one hand, be a precondition of a career in academia and, on the other, be of particular importance for research and management activities in the industrial sector.

German Research Foundation (Deutsche Forschungsgemeinschaft, DFG)

In its theses and recommendations on educating engineers at university level⁴⁰ the DFG maintains that doctoral students should generally complete their doctorate while employed as a research assistant in specific projects. In this way, the doctorate is integrated in and linked to the university's teaching and research activities. This should be retained as the normal doctoral model. In addition, research and doctoral training groups should be set up in areas where interdisciplinary research networks focus on research subjects of mutual interest. The DFG also recommends the formation of Graduate Schools of Engineering to safeguard comparable standards for doctoral training and to offer accompanying seminars and training events.

German Council of Science and Humanities (Wissenschaftsrat)

The German Council of Science and Humanities, too, concludes that many theses are completed as part of the research assistant path, a model that is particularly characteristic of engineering courses.⁴¹ To boost the appeal of this type of doctorate, the Council suggests that students should be relieved of tasks unrelated to their doctorate, clear responsibilities should be defined in the interests of quality assurance and appropriate funding provided to ensure posts are available. In addition, doctoral students should be given time to participate in the study programme of a doctoral training group.

In a recent position paper, the Council made a series of recommendations for assuring the quality of doctorates.⁴² These underline the responsibility staff bear for doctorates, outline standards for supervision, assessment and marking, and describe measures to guard against misconduct.

³⁶ Cf. TU9 2007.

³⁷ CESAER is an international association of some 50 leading European universities and schools specialised in engineering and research.

³⁸ Cf. CESAER 2008.

³⁹ Cf. VDI 2008.

⁴⁰ Cf. DFG 2004.

⁴¹ Cf. German Council of Science and Humanities 2002.

⁴² Cf. German Council of Science and Humanities 2011.

1.5 acatech PROJECT: "FUTURE OF THE ENGINEERING DOCTORATE"

The acatech project "Future of the Engineering Doctorate" took the joint declarations by Europe's science ministers on the Bologna Process as a starting point for an investigation into the associated consequences for the engineering doctorate in Germany. This involves taking specific national characteristics into account with regard to the implementation of the Bologna Process, utilising the opportunities that exist for undertaking a critical examination of the structure, framework conditions and results of the engineering doctorate at German universities, and identifying and making proper use of potential for improvement. This acatech project aimed to determine the existing strengths of engineering doctorates at universities in Germany and define strategies for further improvements.

The support and promotion of academic professionals has been the subject of many studies and investigations (see Berning/Falk⁴³ for a comprehensive list). However, these empirical studies do not contain a sufficient degree of differentiation for the engineering sector. They do not consider the special features of the culture within this particular discipline and, as a result, fail to deliver any reliable statements on the training and support given to academic professionals in the field of engineering.

Consequently, acatech commissioned the Center for Higher Education Policy Studies (CHEPS) at the University of Twente in the Netherlands with the following studies:

- Survey of professors in the fields of engineering and computer science
University professors in a range of engineering disciplines (civil engineering, electrical engineering/information technology, mechanical engineering/process engineering) and computer science were selected, contacted and questioned as part of the survey. In addition to highlighting features of the doctorate environment, the survey was designed to identify ways to safeguard scientific research standards, limit the overall duration of the doctorate and encourage the teaching of soft skills. The survey also examined the size and research intensity of the institute/department, selection procedures for doctoral candidates, how research topics are found and defined, integration in and skills relating to teaching, supervision and additional training, the duration of the doctorate, established strategies for promoting doctorates and proposals for (further) improvements to doctoral training.
- Survey of doctoral degree holders in the fields of engineering and computer science
The survey focused on younger engineers and computer scientists who completed a doctorate only a few years previously before taking up employment in the scientific or business sectors. The views of these former doctoral students would generate ideas for the structure of the doctoral phase in the future. The doctoral degree holders were asked to comment on how they embarked on their doctorate (recruitment, definition of research area), various aspects of the doctoral process (supervision and support, internal and external integration), the duration of the doctorate, the importance of the doctorate for their employment and ways to (further) improve doctoral training.
- Country reports for European countries and the United States of America
To build a detailed picture of specific features of the engineering doctorate across the world, acatech tasked

⁴³ Cf. Berning/Falk 2006.

CHEPS with the compilation of country reports for various European countries (U.K., Italy, France, Sweden) and the U.S.A.

As part of a joint initiative by acatech and the German Engineering Federation (VDMA), representatives from politics, higher education and business met for a round table discussion in April 2007, during which they debated the consequences of the Bologna Process for the engineering doctorate in Germany.

In January 2008, acatech also held an international workshop on the "Future of the Engineering Doctorate in Germany". Experts from Ireland, Italy, France and Belgium reported on the general conditions, structure and results of the engineering doctorate in their respective countries.

The recommendations made by acatech on the future of the engineering doctorate are based on the surveys, investigations and consultations referred to here.

2 SURVEY OF PROFESSORS

2.1 PROCEDURE

The survey was strongly supported by 4ING – the umbrella organisation of the German faculties of engineering and informatics at universities – in order to be able to contact and question as many professors as possible. acatech wrote to all the engineering faculties at German universities asking them to complete the written questionnaire. The completely anonymous survey was carried out between November 2007 and January 2008. The partially standardised questionnaire for professors covered a total of 37 questions (both closed and open) and provided space for additional comments.

2.2 DATABASE

A total of 417 professors from various engineering and computer science disciplines participated in the survey. Almost a third of those questioned⁴⁴ assigned themselves to mechanical engineering/process engineering (32 %), while computer science accounted for the second largest group (25 %). These were followed by civil engineering (18 %) and electrical engineering/information technology (16 %). The remainder (8 %) assigned themselves to other subject areas, with geodesy/geoinformation and mechatronics recurring most frequently.

This sample covered a broad spectrum of institute sizes in terms of the number of research assistants employed. The professors also had very different levels of experience, ranging from those who had held their chair since before 1990 to those who were appointed after 2000.

Between them, the professors had successfully supervised 2,868 doctorates over the preceding five years. Mechanical engineering/process engineering accounted for the largest discipline among these doctorates (50 %).

The figures shown also include doctorates done by foreign students. Over the last five years, foreign students successfully completed a total of 451 doctorates, or 15 % of the overall total. With 201 completed doctorates, mechanical engineering/process engineering accounts for the largest number of foreign doctoral degree holders.

2.3 RESULTS

The key results of the survey of professors are detailed below:

- Professors use a range of strategies and tools to recruit doctoral candidates. Students and/or graduates at the professors' own universities are particularly important, with one in two professors predominantly recruiting their doctoral candidates from these groups. The selection process is based to a large extent on the interview, but also the applicant's performance in his Master's thesis and as a student research assistant within the department.
- Research areas for the doctorate are chosen in a number of different ways. 62 % of professors say that, to a certain extent, they give their students a rough outline of a research topic and then work with them to refine this during the course of the doctorate. 24 % say they work with their doctoral candidate to identify a topic, based on an initial suggestion made by the student. 14 % of professors use both approaches.
- Overall, 89 % of professors say that they themselves are largely responsible for supervising their doctoral students. 61 % draw up work and time management plans to ensure the doctorate is completed on time. 92 % ask their doctoral candidates to provide regular progress reports.
- Various methods are used to provide training during the doctoral phase. Some of the most common include

⁴⁴ This refers to professors who responded.

providing regular, personal support for doctoral students, getting them involved in research work within the department, and colloquiums for doctoral candidates. 72 % of professors feel these colloquiums are particularly beneficial. Around half of those surveyed also mentioned other education and training events, such as subject-specific lectures. These mainly promote subject-specific learning, with the acquisition of soft skills playing a lesser role.

- 73 % of professors report that, in addition to working on their thesis, doctoral candidates often or very often act as supervisors for undergraduates and students working on their degree dissertations. More than half also say doctoral students participate in other research projects. In comparison, organising events or networks in collaboration with other doctoral candidates plays only a minor role.
- 50 % of professors prepare their doctoral candidates for teaching roles and over two thirds assess their candidates' teaching performance. Doctoral students prepare for teaching responsibilities by taking part in appropriate training sessions. However, the most important factor is the personal support professors provide in developing and discussing teaching materials with doctoral students and improving their rhetorical skills.
- 95 % of professors expect doctoral candidates to successfully publish material before they submit their thesis. The most preferred media are contributions to international conferences (92 %) and papers in reviewed international journals (72 %). A quarter of professors specify a minimum number of publications to be achieved before the end of the doctorate. On average, they expect students to publish 4.3 pieces.
- Based on the professors' experience, the average period required for working on a doctorate is 4.5 years, with the doctorate as a whole lasting an average 4.8 years.
- According to the survey, it takes an average of 11 months to find and define a research topic. If the professor provides the candidate with a specific research area, it takes 9.7 months to compile a research topic. If the candidate selects their own area of research, the time required increases to 13.7 months.
- Only around 36 % of professors plan to make changes to doctoral training in their department. The introduction and/or expansion of colloquiums for doctoral candidates and opportunities for further training, particularly in soft skills, play a key role here.
- A large proportion of professors do not think there is any need for more changes to the doctoral phase. They feel it is more important to improve the framework conditions for doctorates by securing finances or cutting back on administrative work, for example.
- The professors' feedback on proposals to make the engineering doctorate a third level of study is predominantly critical, with only a few positive comments. They criticise any increased regulation that would fundamentally alter the nature of the engineering doctorate, with the doctoral phase no longer serving as a first stage in employment. In contrast, those in favour of this move cite opportunities for a systematic, interdisciplinary approach to doctoral training.

3 SURVEY OF DOCTORAL DEGREE HOLDERS

3.1 PROCEDURE

The survey of doctoral degree holders was based on a written questionnaire of 30 questions with a similar structure to that used for the professors. The questionnaire was sent to doctoral degree holders in the fields of engineering and computer science now employed in the private sector. All of them had completed their doctorates between two and five years before the survey was carried out. Some of the doctoral degree holders surveyed were part of the Association of German Engineers (VDI), which provided valuable support in this phase of the project. acatech wrote to former doctoral candidates asking if they would be willing to take part in this anonymous survey, which was carried out between November 2007 and February 2008.

3.2 DATABASE

The survey of doctoral degree holders returned a total of 328 usable questionnaires. Over half of those questioned⁴⁵ held a doctorate in mechanical engineering/process engineering, 17 % in electrical engineering/information technology, 9 % in civil engineering and 8 % in computer science. Other disciplines accounted for 11 %, mainly geodesy and geoinformation and materials science.

With 92 % male respondents and 8 % female, the group reflects the familiar gender split in engineering disciplines. 84 % of all those questioned completed their doctorate as part of a department and/or a university institute. Other models were the exception rather than the rule, with just 5 % writing their thesis under the auspices of a research institute/department in the industrial sector and 6 % in a non-university research institute. Slight variations are also evident between the various disciplines. Those with doctorates in civil engineering showed an above-average tendency to have participated in a research training group (10 %), while

those in the field of computer science often completed their thesis at an industrial research institute.

3.3 RESULTS

The key results of the survey of doctoral degree holders are detailed below:

- Prior to the doctoral phase, two thirds of the respondents had had previous contact with the department where they then wrote their thesis. For this group, this was also the path that led to their acceptance as doctoral candidates.
- A third of those questioned were able to determine their research topic completely independently, while 55 % were given a rough outline which they were then able to refine. Only one in ten were given a fully-formed topic. Those who did their doctorate in a non-university research institute were more likely to have been given a topic to work on.
- 75 % were supervised by a professor and 25 % by an experienced research assistant. The majority give positive feedback on the support they received from their supervisors during the doctoral phase.
- During the doctoral phase, 50 % had regular opportunities to participate in a colloquium for doctoral candidates, while 41 % also had the option of taking part in other education/training events for doctoral students. These mainly included subject-specific lectures and seminars on rhetoric and presentation skills.
- In addition to working on their thesis, doctoral degree holders who did their doctorate as part of an academic department were involved in a wide range of research and teaching activities. Above all, these included supervising students (63 %), teaching (52 %) and participating in other research activities parallel to the doctoral thesis (53 %).

⁴⁵ This refers to doctoral degree holders who responded.

- The amount of time consumed by these activities differed. Half of doctoral degree holders say they spent up to 50 % of their work time on these activities. The other half estimate such activities accounted for 75 % or more of their time.
- During the doctoral phase, almost all of those surveyed took an active part in scientific conferences (93 %), and the majority also published material during this period. On average, they participated in around eight conferences and published approximately eight pieces of work.
- 55 % of doctoral degree holders also state that they were expected to have work published before submitting their thesis, preferably in the form of papers in internationally reviewed journals and contributions to internationally reviewed conferences.
- According to the survey, the average duration of the doctorate from the beginning of the thesis to its submission was 4.4 years, and 4.8 years to the time of the oral examination.
- Virtually all the doctoral degree holders were in employment at the time of the survey, with 93 % employed by third parties and 7 % working on a freelance basis. Most were employed in the private sector (74 %) in not only research and development roles, but also management positions.
- 62 % had leading management or middle management positions at the time of the survey. In particular, those who completed their doctorate less recently were often found to be in leading positions. 10 % of those questioned were employed outside Germany.
- Only half of doctoral degree holders felt their doctorate was essential for their current employment. In contrast, 78 % considered their chosen subject-specific area as an important requirement for their professional role in the workplace.
- In some instances, there were clear discrepancies between the qualifications acquired by the doctoral degree holders and the actual professional requirements of their job. This applied in particular to skills such as cooperation, motivation and management of staff, organisational abilities and foreign languages. According to the survey, in these areas professional job requirements often exceeded the qualifications and skills acquired during the doctoral phase. However, doctoral degree holders stated they are seldom required to use their scientific expertise to the full in their current employment.
- Overall, the doctoral degree holders say that completing their doctorate marked a key stage in their life. Given the choice, 97 % would choose to do a further doctorate. Above all, they feel the doctorate has been important to their personal development and to intensifying the depth of their knowledge in their chosen field.
- The doctoral degree holders identify the freedom they enjoyed in terms of defining a research topic and the overall process as some of the positive features of the doctoral phase. Many also refer to the variety of tasks they were involved in during their doctorate.
- The main negative features are deemed to be university bureaucracy and the supervision of the thesis. The issues identified include a lack of time on the part of supervisors and difficulties in agreeing a clear, structured research topic with supervisors as quickly as possible in the early stages of the doctorate. The doctoral degree holders also criticise the fact that they had few opportunities to acquire soft skills during their doctorate.
- The suggestions for improvement made by the doctoral degree holders can be divided into two categories. On one hand, they call for the doctoral phase to be more clearly structured, with binding timetables and agreements drawn up with the supervisor to ease general orientation throughout the process. They also feel the content of the doctoral phase should be expanded, with events designed to teach soft skills integrated into the doctorate along with more internationality and interdisciplinary aspects.

4 SYNOPSIS OF THE SURVEYS OF PROFESSORS AND DOCTORAL DEGREE HOLDERS

A combined synopsis of the two surveys reveals the main issues and areas for development in the engineering doctorate. The strengths and weaknesses identified by the participants form an important basis for the recommendations made by acatech on the future of the engineering doctorate.

STRUCTURE

As far as university professors are concerned, the current model of the engineering doctorate has proved its worth. There are more professors who reject further reforms to doctoral training than support the introduction of a more strictly structured curriculum in the form of research training groups and graduate schools, for example.

For doctoral degree holders, the need to enrich the content of the doctoral phase outweighs calls for structural changes. A large proportion of the participants call for a stronger focus on training soft skills, especially basic business knowledge, HR management, project management and foreign language skills.

In terms of changes to the doctoral training structure, there is a particular desire for improvements to the way time is allocated during the doctoral phase and for restrictions on extra tasks undertaken in addition to the thesis. However, doctoral degree holders would not wish these structural changes to be implemented at the cost of increased regulation of the doctoral phase. Instead, there is general support for the retention of the current model, where the engineering doctorate is carried out within the framework of employment as a research assistant in an academic department.

ACQUIRED SKILLS

The doctoral phase provided the respondents with opportunities to acquire a wide range of skills, including presenting results to an audience, analysis as well as written and oral communication skills, and the application of scientific methods. These were each named by three quarters of those surveyed.

In contrast, the demands made of doctoral degree holders in their professional roles reveal that, in some instances, a very different skill set is expected. First and foremost, this includes an ability to cooperate with others, analytical skills, good written and oral communication and organisational abilities. In addition, the level of skill acquired in the various areas is often insufficient for the requirements of the professional work environment. This discrepancy is particularly evident in relation to cooperative skills, the ability to work in a team, foreign language skills and organisational skills.

This area reveals the greatest divergence of opinion between professors and doctoral degree holders on the quality of the engineering doctorate at German universities. Many professors view the tasks undertaken in parallel to the thesis – and the skills thus acquired – as “on-the-job training” that will stand doctoral candidates in good stead in their future employment. However, doctoral degree holders state there is a large discrepancy between the level and nature of the skills acquired and those expected in the professional work environment.

RECRUITMENT AND MOBILITY OF DOCTORAL CANDIDATES

Doctoral students are most often recruited via the traditional paths. Most professors recruit their doctoral candidates from within the student body at their own university. Prior to embarking on the doctoral phase, two thirds of doctoral degree holders had had previous contact with the department where they subsequently wrote their thesis.

40 % of professors select their doctoral students from among graduates at their own and other universities, while 10 % mainly appoint doctoral students from other universities. As a result, there are opportunities for graduates to switch location to do a doctorate following their degree. This opportunity is taken up by some graduates, albeit in limited numbers – overall, around one third of doctoral degree holders moved university to do their thesis.

RESEARCH TOPIC

The core requirements for a doctorate include developing a concept, research topic and questions to be addressed in the thesis. 62 % of professors to some extent dictate the subject of the doctorate to their students, while 24 % usually suggest a topic. For their part, doctoral degree holders say they were given a high degree of autonomy. 35 % selected their research topic themselves, while 55 % were given a rough outline of a topic for their thesis, but ultimately developed the proposal themselves.

TIME TAKEN TO DEFINE THE RESEARCH TOPIC

A transparent, speedy approach to developing a research topic can make the doctoral process a great deal more straightforward. Regardless of the approach taken,

professors and doctoral degree holders alike agree that it takes nearly a year to draw up a topic (11 months on average).

SUPERVISION, SUPPORT AND SOFT SKILLS

Overall, 89 % of professors say they are personally responsible for supervising their doctoral students. This largely reflects the view expressed by doctoral degree holders. A total of 75 % say they were supervised by a professor, and the remainder by experienced research assistants.

The majority of doctoral degree holders say the level of support received from their supervisors during the doctoral phase very much corresponded to their expectations. The professors share this view and feel the supervision they offer covers a wide spectrum and is well adapted to the needs of doctoral students. However, closer examination of the type and range of supervision available reveals certain differences of opinion between professors and doctoral degree holders. Doctoral degree holders give very positive feedback on active participation in scientific congresses and the support they received in publishing papers, drafting their thesis, undertaking research and creating opportunities for cooperation. For professors, providing personal support to their doctoral candidates on a regular basis and involving them in departmental research activities are viewed as particularly proven strategies.

Statements on colloquiums for doctoral candidates differed considerably. Overall, 72 % of professors regularly hold a colloquium within their department, although only exactly half of doctoral degree holders say they were regularly able to participate in such colloquiums during their doctorate.

Professors and doctoral degree holders reveal very similar opinions on additional education and training activities.

A total of 52 % of professors believe additional courses such as subject-specific lectures, rhetoric, languages, research management and management skills are made available to their doctoral students. A comparable, if slightly lower, number of doctoral degree holders agree with this (41 %). The range of activities is also similar, covering subject-specific lectures, training in rhetoric and presentation, language courses and research management skills.

CONTRIBUTIONS TO CONFERENCES' AND PUBLICATIONS

In addition to involvement in activities at the relevant institute, participating in conferences and publishing research results are other key ways of establishing doctoral students as part of the scientific community. The professors' expectations and the retrospective evaluations provided by the doctoral degree holders are virtually the same. 95 % of professors expect their doctoral candidates to have published work prior to submitting their thesis. 86 % of doctoral degree holders confirm they published other material in addition to their thesis. In total, 93 % of doctoral degree holders actively participated in (several) scientific conferences during their doctorate. This corresponds to the expectations expressed by 92 % of professors, who view contributions to international conferences as the preferred form of publication.

DURATION OF THE DOCTORATE

Professors and doctoral degree holders provide very similar feedback on the duration of the doctorate. Estimates from both groups put the average duration at 4.8 years from the start of the doctorate to the oral examination. Of that, the average period of time spent working on the doctorate itself is estimated by the professors to be 4.5 years (doctoral degree holders: 4.4 years). The average period between the

submission of the thesis and the oral examination is around 4 months (doctoral degree holders: 5 months).

TASKS NOT DIRECTLY RELATED TO THE DOCTORATE

Tasks not directly related to the doctorate are often viewed as a disproportionate burden on doctoral candidates, distracting them from their own thesis. However, they can also be viewed as "on-the-job training". Based on the survey, the tasks most frequently undertaken by doctoral students parallel to the thesis are supervising and supporting undergraduates, contributing to additional research projects and teaching. The professors agree with this, even putting the tasks in the same order. According to the majority of professors, these tasks occupy up to 50 % of the doctoral students' work time. Doctoral degree holders put this figure higher, with just half saying they spent an average of 50 % of their work time on these additional tasks. The remainder estimated that such tasks took up 75 % or more of their time.

SUMMARY

Professors and doctoral degree holders are generally united in their positive evaluation of the engineering doctorate in Germany. Nevertheless, their opinions differ on the acquisition of soft skills and the volume of tasks not directly related to the doctorate (mostly organisational and administrative tasks, provision of services, and teaching and additional research obligations not part of their own doctoral project). Neither group shows a majority consensus in favour of a more strictly structured doctoral phase with accompanying training and education courses, the introduction of different selection procedures or the integration of doctoral candidates in doctoral training groups.

5 COUNTRY REPORTS: EUROPE AND THE UNITED STATES OF AMERICA

Many European countries have initiated reforms to doctoral training as a result of the Bologna Process. acatech used this as a springboard for an international workshop entitled “Future of the Engineering Doctorate in Germany” in January 2008. Members of the project team met with experts from Ireland, Italy, France and Belgium to discuss the general conditions, structure and results of the doctoral phase in engineering and computer science.

To build a detailed picture of particular features of the engineering doctorate internationally, acatech also tasked the Center of Higher Education Policy Studies (CHEPS) at the University of Twente in the Netherlands with the compilation of reports on various European countries (U.K., Italy, France, Sweden) and the United States of America.

The following comparative summary is based on five country reports⁴⁶ and the background information and discussion outcomes of the aforementioned workshop.⁴⁷ The countries represent different traditions in higher education and apply different principles in the promotion of academic professionals. Doctoral training may have undergone significant changes in all these countries during the 1990s and into the 21st century, but there are still many features indicative of a “convergence of the systems”. In all the countries studied, doctoral training proved more strongly structured, with universities setting up dedicated institutes responsible for selecting, supervising, training and examining doctoral candidates.

The primary difference between the engineering doctorate at German universities and in other countries is the appointment of doctoral students as research assistants as part of the research assistant path, and the central role played by project-based cooperation between the business and scientific sectors. At German universities, the acquisition of ad-

ditional skills and qualifications by doctoral students still lags behind the level normally expected or aimed for in the international context.

On average, the time taken to complete an engineering doctorate is 4.6 years. In the context of an international comparison, the duration of the doctorate in Germany is by no means disproportionately long, but in fact fairly average. The average German candidate completes his doctorate aged 33.9 years⁴⁸, not significantly older than doctoral students in the countries detailed below. On closer examination – and certainly in terms of an international comparison – criticisms that the German doctorate lasts too long and doctoral students are too old do not hold firm. According to the professors surveyed, the drop-out rate lies at an average of 13 %, similar to that in France and considerably lower than the figures for the U.K., Italy, Sweden and the U.S.A.

ORGANISATION: GRADUATE SCHOOLS AND OTHER STRUCTURES

In terms of the structure of the doctoral phase, the countries examined have shifted from the traditional one-on-one supervision of doctoral candidates to more formal, regulated and standardised models. This is evident in the emergence of specific organisational structures such as graduate schools and research training groups.

Graduate schools in the U.S.A. are organised on a two-tier basis. The first leads to a *Master's degree* following a course of study normally lasting two years, while the second builds on this and consists of a three- to four-year course concluding in a doctorate. Both tiers feature a comprehensive programme of optional and mandatory courses.

⁴⁶ The detailed English-language country reports are available in the project report (acatech 2008).

⁴⁷ The following remarks also benefit from country-specific information on doctoral models collected by Kupfer/Moes 2004.

⁴⁸ On average, undergraduates at German universities are 21.3 years old when they begin their studies. The average age for graduates is 27.8 years. Doctoral students generally complete their doctorate aged 32.7 years (source: Federal Statistics Office 2011a and 2011b, all figures shown are for 2010).

The organisational bodies responsible for doctorates in France are known as *écoles doctorales*. First introduced at the end of the 1980s, these have been supported more intensively and undergone further expansion in the period since 1998 in an effort to establish more structured models for and improve the quality of doctoral training. Overall, the practical relevance of the *écoles doctorales* for doctoral students is deemed to be very varied. Some function as a key organisational centre for communicating scientific knowledge, while others are more loosely connected structures whose own significance is clearly subordinate to their allegiance to a specific research group. There are also very different approaches to mandatory participation in courses.

Sweden's *National Graduate Schools* primarily seek to bring together different doctoral students from within a specific discipline from either one or more universities.

Traditionally, doctoral training in the U.K. was fairly unstructured, with no explicit teaching programme for doctoral candidates at British universities. This changed at the beginning of the 1990s with the establishment of *graduate schools*. A *Research Master's course* is often required prior to embarking on a doctoral programme (*Ph.D. course*). In addition to the research-oriented *Ph.D.*, programmes for a *professional* or *taught doctorate* have also been introduced in recent years.

A small number of U.K. universities offer courses earning the academic title *Doctor of Engineering (EngD)*. This first appeared in 1992 and is funded by the *Engineering and Physical Sciences Research Council (EPSRC)*. They aim to dovetail science and industry, with doctoral students generally being placed in a company where they work on industry-oriented research projects under the supervision of a member of the university teaching staff. The *EngD* is often awarded based on a portfolio of research projects rather than a single thesis.

The *New Route Ph.D* (or integrated Ph.D.) was launched in the U.K. in 2001. This programme mainly consists of three (integrated) elements, i.e. courses on research methods and specialisation, training in key transferable skills and work on the thesis. Students can embark on this programme immediately after completing their Bachelor's degree. In Germany, this model has become known as the *fast track Ph.D.*

COLLABORATION WITH INDUSTRY

In the U.K. and U.S.A., doctoral training is not generally closely interwoven with the industrial sector. The doctoral phase in the U.S.A. is criticised for being very much weighted towards academic criteria, even though the majority of those who gain engineering doctorates go on to seek work in industry. Around 73 % of doctoral degree holders in the U.S.A. work in the industrial sector, 14 % in institutes of higher education and around 11 % in federal organisations. In the U.K., education is the most important area of employment for engineers with doctorates, with 44 % pursuing a career in this sector. 23 % opt for employment in the industrial sector and 19 % in the fields of finance and management. The introduction of the *Doctor of Engineering (EngD)* in the U.K. has led to stronger ties between universities and industry.

An increasing number of doctorates in France are done in conjunction with the industrial sector, and this will be promoted further still as a result of the CIFRE agreement (*conventions industrielles de formation par la recherche*). This agreement aims to use co-financed doctoral posts to expand research in specific areas of industry and give companies an opportunity to enter into cooperation with public research laboratories. This research work serves as preparation for the doctoral thesis. Around 10 % of students doing a doctorate in engineering are funded under the CIFRE agreement.

ACQUISITION OF NON-SUBJECT-SPECIFIC SKILLS

In all the countries examined, doctoral students take part in a largely mandatory programme of study run in parallel to the doctorate. Some of this is done prior to embarking on their individual research project, and some at the same time.

Ph.D. courses at U.S. universities begin with a structured programme lasting around three years. After a certain period (usually two years) and the completion of most of the programme, the student can earn a Master's degree. This is an ancillary and interim step in terms of the overall scientific career path. This structured phase ends with the *qualifying or field exams*. Once they have formally presented their thesis project to a committee, the doctoral candidates focus fully on their own research. Short-term positions known as *teaching and research assistantships* are an integral part of the doctoral phase. In response to continuing criticisms regarding inadequate training in core skills, universities in the U.S. are now revising their doctoral programmes.

One new initiative in the U.K. is the *GRAD programme* funded by the country's Research Councils. This programme offers courses all over the U.K. to support postgraduates' personal and professional development. Participation in the *GRAD programme* is mandatory for doctoral students with a Research Council scholarship.

The *écoles doctorales* launched in France at the end of the 1980s were intended to create a more defined structure for and improve the quality of doctoral training. In terms of additional education and training, students are required to complete two scientific modules in the first year of their doctorate and two further career-based modules during the second year.

PERFORMANCE DATA (DURATION, DROP-OUT RATE, AGE UPON COMPLETION)

In all of the countries examined, the engineering doctorate takes roughly the same amount of time to complete as doctorates in other disciplines. The figure is between 3 and 4 years in France and between 3.5 and 4.5 years in Sweden. Including the time taken to gain their Master's degree, doctoral candidates at U.S. universities complete their doctorates after around five years. The *Research Councils* in the U.K. have recently extended funding for doctoral projects from 3 to 3.5 years.

The *drop-out rate* varies significantly between the different countries. The rate in Sweden is around 40 %, although the trend is clearly improving due to reforms to doctoral training. In Italy, the drop-out rate has been falling slightly for some years and, at around 25%, is currently slightly higher than that in the U.K. (20 %). At 40 %, the overall drop-out rate for doctoral programmes in France is unusually high, making the 12 % rate for engineering comparatively low.

In all these countries, engineers are of a similar age to or younger than their counterparts in other disciplines when they complete their doctorates. The youngest are in the U.K., where 44 % are aged under 25 years when they receive their doctorate. The average age is between 28 and 29 years in France, 27 and 30 years in Italy, and 31 years in Sweden (in Sweden, the average age for students completing doctorates in all disciplines is between 35 and 36 years). In the U.S.A., the average age for doctoral students in engineering disciplines taking their examination is 30 years (47 % are between 26 and 30 years and 34 % between 31 and 35 years).

6 RECOMMENDATIONS

The overall picture of the process and outcomes of the engineering doctorate in Germany is very satisfactory. Universities train highly-skilled academic professionals in the engineering disciplines, and the doctoral degree holders enjoy an excellent professional reputation in scientific and business circles both nationally and internationally. Doctoral degree holders play a key role in the innovation process as researchers, developers and managers, creating new processes and products based on the natural and technical sciences.

At German universities, the vast majority of engineering doctorates are done within the framework of employment as a research assistant and have a strong focus on research, teaching and project work⁴⁹ carried out on a largely independent basis. This ensures doctoral students develop a comprehensive range of skills and distinguishes German engineering not only from its international counterparts but also from other scientific disciplines.

Doctoral students play a particularly important role in the interaction between business and science. They are the main conduit for project-based cooperation between universities and industry. Among other things, this facilitates the transfer of knowledge and technology essential in the development of new innovations. Former doctoral students now working in the industrial sector are also a key element in this fruitful interaction and in building networks between business and science. They inject their professional experience back into the university environment and, in return, gain important stimuli for their careers as researchers and managers.

To ensure the skills acquired by doctoral students in engineering disciplines can continue to meet the requirements of science and business and the expectations of all the

parties involved, acatech has drawn up the following series of overarching recommendations for the various phases in the doctoral process, including specific suggestions for improvement. In the first instance, these are designed to maintain and further consolidate the excellent quality of the engineering doctorate in Germany. Positive experiences of all aspects of the engineering doctorate should feed into this and – where necessary – be intensified, expanded or reviewed. Overall, these recommendations are intended as a guideline for the engineering doctorate, summarising existing, proven features alongside beneficial new elements.

Consequently, the proposals made here for the further improvement and consolidation of the engineering doctorate will generate different responses. In cases where the recommendations are already being implemented in practice, they will be seen to affirm existing models and approaches. In others, the recommendations could provide valuable stimuli for the further development of the engineering doctorate.

In these recommendations, acatech assumes that the research assistant path has proved its continued worth. However, there are other approaches to the doctorate, including participation in a research training group/graduate school, other forms of structured doctoral models and doctorates done "externally" as an employee in an institute linked to the university or in the industrial sector.

acatech has drawn up twelve recommendations for the further development of the engineering doctorate:

⁴⁹ Project work refers to research projects carried out for public bodies or the industrial sector over a limited period of time, either individually or in collaboration with others.

6.1 OBJECTIVE OF THE DOCTORATE: INDEPENDENT RESEARCH

The doctorate serves as evidence of the ability to carry out independent scientific work. Doctoral candidates are expected to demonstrate that they are able to identify and prepare a scientific proposal, work on it using scientific methods and present the results clearly and precisely, thus making a contribution to knowledge in that particular field.

General recommendations on the conditions governing the doctorate

- Universities must continue to boost the appeal of the doctorate and support the doctoral process by providing doctoral students with adequate facilities, including the equipment, consumables and technical staff essential to independent scientific work.
- Integrating doctoral students into an active scientific environment is a key success factor in the doctorate. Doctoral candidates and their chosen topic should become part of research activities at the relevant institute and contribute to its key areas of scientific interest. Equally important is integration in the wider research environment, for example through cooperation with business, other universities and research institutes, active participation in (international) scientific networks and the presentation and publication of candidates' own research results.

Courses of study undertaken prior to the doctoral phase give students in the field of engineering the basic specialist and methodological skills required to prepare and successfully complete a doctorate. In addition, working on what is usually a highly specialised thesis may require further fundamental theoretical and practical knowledge. This may improve the effectiveness of research activities

and ensures the time invested in them directly benefits the overall research result.

Recommendations on the acquisition of other subject-specific skills

- The acquisition of additional subject-specific skills during the doctoral phase can be useful in promoting the autonomy and expertise of doctoral candidates.
- In this respect, universities should use existing courses to provide doctoral students with a greater insight into their own subject and related disciplines.
- Supervisors should actively encourage doctoral candidates to participate in accompanying courses. For their part, candidates should attend these regularly and conscientiously.
- However, completing such accompanying courses should not be made mandatory for doctoral students.

6.2 OBJECTIVE OF THE DOCTORATE: ACQUISITION OF NON-SUBJECT-SPECIFIC SKILLS

Today more than ever, doctoral degree holders in the engineering disciplines are required to have a range of non-subject-specific skills. They must be able to devise, acquire and organise projects, build and manage project teams and communicate innovations and their transfer. They must also be able to identify the scientific tasks contained within a practical problem, conceive and plan a suitable approach and the necessary scientific tools and methods, accurately record results and demonstrate the benefits of their work to that specific area of research. This is even more important given that academic research is by no means the only career avenue open to those with an engineering doctorate. As universities qualify a very large proportion of students for the non-university employment market (i.e. business and industry), it is crucial that the doctorate phase also prepares

candidates for research and leadership roles in this environment.

The survey of doctoral degree holders revealed clear shortcomings in the field of non-subject-specific skills.

Recommendations

- During the doctoral phase, candidates should acquire a range of skills parallel to their work on the doctorate itself.
- These include business knowledge (assessing cost-efficiency requirements, costing), legal skills (law of sales, patent law), soft skills (communication skills such as chairing and hosting discussions, project management abilities, leadership skills, language skills) and an awareness of career planning (familiarisation with potential areas of employment in consultation with bodies such as the university career centre, generating employment prospects and development opportunities for particularly gifted doctoral degree holders).
- Doctoral students gain these key skills by participating in research projects, getting involved in teaching activities and generally being part of an active scientific environment ("on-the-job training"). Parallel to this, personal development programmes organised by the relevant institute or by other parties can be used to offer education/training courses specially tailored by the universities to the needs of doctoral candidates.
- Doctoral students should be able to independently select the training courses suitable for them and discuss these options with their supervisor. Participation in such courses should be covered in the agreement concluded between student and supervisor.
- Doctoral candidates should themselves plan the schedule for the acquisition of these additional skills and coordinate them with the overall doctoral project. They should take advantage of at least two of these courses according to their interests/requirements.
- However, the range of training-style elements on offer should not be excessive, nor should their provision be to the detriment of research activities, as this would ultimately weaken the employment aspect of the doctoral phase. This potential problem must be considered on a case-by-case basis when integrating any additional courses of this type.
- Credits should not be awarded for participating in additional lectures or performing other work. However, doctoral students should be issued with confirmation of participation and any examinations taken if they so request.

6.3 ADMISSION

In contrast to the individual selection of doctoral candidates, formal admission to a doctoral course is subject to legislation that, although not standardised across all the different German states, nevertheless prescribes specific requirements. In addition to the general requirements of employment law, candidates seeking positions as research assistants are required to have completed a graduate degree. Admission to the doctoral process requires a *Diplomabschluss* (equivalent to a Master's degree) from a university or a *Masterabschluss* (Master's degree) from a university or *Fachhochschule* (university of applied sciences). In exceptional cases, particularly well-qualified graduates with a *Diplomabschluss* from a university of applied sciences, or graduates with a Bachelor's degree⁵⁰ from any institute of higher education may be admitted as part of an aptitude assessment. This normally requires the candidate to undertake additional studies over the course of several semesters.

⁵⁰ In their report on the accreditation of Bachelor's and Master's degrees "Länderübergreifende Strukturvorgaben für die Akkreditierung von Bachelor- und Masterstudiengängen" (KMK 2003), Germany's ministers of education and cultural affairs stated that holders of a Bachelor's degree may be directly admitted to a doctoral course via an aptitude assessment without being required to gain a further degree.

Recommendations

- The basic requirement for admission to a doctoral course is the prior achievement of a Master's degree (or the Diplomabschluss from a university).
- The requirements for formal admission to a doctoral course should be laid out in the doctoral degree regulations. This applies in particular to processes used to establish that degrees held by applicants are equivalent to the Diplomabschluss and/or Master's degree of the university where the doctorate will be done.
- As stipulated in the relevant legislation, admission to doctoral courses based on a Bachelor's degree should be considered for only the most outstanding students and granted only in particularly exceptional cases. It is recommended that graduates with a Bachelor's degree take part in an aptitude assessment to gain skills equivalent to those achieved during the Master's phase of a consecutive degree. This can be done either prior to or in parallel with the doctorate.
- The specific structure and procedure involved in the aptitude assessment should be defined in the relevant doctoral degree regulations.
- The traditional process where professors select gifted undergraduates and graduates of the own university should be expanded with institutionally organised advertising and admission procedures ("selection based on excellence"). However, the final decision must rest with the member of the university teaching staff who will be responsible for supervising the thesis.
- Universities should also make it easier for particularly talented graduates from universities of applied sciences to qualify as doctoral candidates. Any decision regarding admission should be taken after examining the candidate's application based on the valid doctoral degree regulations.
- In the interests of improving the mobility of young academics, university staff should intensify efforts to gain doctoral candidates from outside the student body at their own university. According to the results of the survey, recruitment within the same university currently plays a key role, with one in two professors mainly selecting their research assistants and/or doctoral candidates from this group. Only around one in every three doctoral degree holders changed universities to do their doctorate.

6.4 SELECTION

One of the crucial factors used to determine the quality of an institute or university is the standard of its output. Particular attention must therefore be paid to how doctoral candidates are selected.

Recommendations

- In essence, doctoral degrees should only be open to particularly talented graduates who have completed the required stages of study, or those who have achieved excellent results outside university-based research institutions.

6.5 STRUCTURE

The current typical model of the engineering doctorate in Germany generally works very well. Shared by professors and doctoral degree holders alike, this view is closely bound with the research assistant approach to the doctorate, which is the preferred model for around 90 % of all engineering doctorates.

Recommendations

- As it is so widespread, the research assistant path is the typical model for the engineering doctorate.

Doctoral candidates complete a piece of original scientific research within the framework of employment as a research assistant. In conjunction with collaborations with industrial partners, the research assistant path gives doctoral students a balance between practice-oriented and scientific research work.

- In addition to the research assistant path completed under the auspices of the university, doctorates can also be done as part of research training groups, graduate schools or other structured doctoral models. In contrast to the research assistant path, candidates who pursue one of these options receive a scholarship rather than working as a research assistant within an institute or department.
- The coexistence of both approaches is important, as combining the established research assistant path with structured doctoral models under the auspices of one scientific institute creates a mutually beneficial relationship.
- Each university must structure its doctoral models within the framework of its own autonomous status.
- One other particular aspect of the engineering doctorate is the provision made for external candidates who have no formal ties with the university prior to the start of the official examination process. These candidates may be employed in the industrial sector or by institutes that cooperate with the university.

In the case of doctorates completed in the industrial sector, it is important to achieve a fair and appropriate distribution of tasks between industry and higher education, to integrate the doctorate into university research activities and to ensure that scientific responsibility is held exclusively by the university supervisor. Doctorates linked with industry should be based on a shared research project, with the doctoral degree being completed in form and scope in accordance with the normal conditions and standards required by the su-

pervising institute. This form of cooperation has proved highly beneficial in practice.

- As part of efforts to promote life-long learning, make career paths more flexible and improve professional development opportunities, engineers should have the option to switch to a scientific/research career or complete a period of scientific/research work at a later stage in their professional working life. Provision is already made for this in many cases, but the reciprocal relationship between the scientific and business sectors needs to be improved further still.

6.6 AGREEMENT BETWEEN DOCTORAL CANDIDATE AND SUPERVISOR

Independent research is a core element of gaining a doctorate. However, academic professionals also require regular, organised support:

- to ensure the content of their work is of a high quality and
- to define the responsibilities of the doctoral candidate and the supervisor throughout the duration of the doctorate.

Recommendations

- The doctoral student and supervisor form a "research community" and, as such, should as early as possible conclude an agreement clarifying their rights and obligations. At the very least, this agreement should cover the following:
 - An outline of the research topic/area.
 - A schedule for the doctorate, including key milestones in the project.

- An estimate of the material, financial and personal resources probably required, including the means to acquire these.
 - Definition of additional strategies to support the doctoral process, covering an appropriate scope and range.
 - Doctoral candidates should be obliged to submit summary reports on a six-monthly basis and to give a presentation as part of a colloquium for doctoral students at least once a year to report on the progress of their research and outline how they plan to proceed.
- Supervisors should help doctoral candidates to present and discuss their research work within national and international research communities. Throughout the doctorate, candidates should:
- give presentations at national and international conferences, including at least one delivered in English and
 - publish specialist scientific texts.

This should also include the publication of partial results of the thesis (prior publication), giving doctoral students an opportunity to make these the subject of scientific discussion as early as possible.

- If desired, an additional (experienced) scientist can be appointed in a mentoring role. The doctoral candidate should provide regular progress reports to his mentor, thus integrating that mentor into the doctoral process.
- The university supervisor and scientific mentor should work together to assess (interim) reports submitted by the candidate.
- Doctoral students should agree a set of terms and conditions for good scientific practice with their supervisors.⁵¹

6.7 DURATION OF THE DOCTORATE

In the recent past, criticisms that higher education courses last too long have been the subject of much public debate in Germany. One recurring claim is that academic professionals are "too old". The allegedly high average age of doctoral degree holders is often viewed as a particularly obvious symptom of the structural shortcomings said to exist within Germany's academic system. With an eye to international development, Germany's politicians are eager to reduce the duration of courses and produce a younger generation of academic professionals.

As revealed in the surveys of professors and doctoral degree holders, the average duration of the engineering doctorate in Germany (around 4.5 years) is comparable to other countries. Even so, acatech supports all efforts to promote a swift, targeted approach to doctoral courses in the engineering disciplines.

However, it is important to bear in mind that any move to reduce the duration of the doctorate could potentially compromise the quality of the scientific work produced or prevent candidates acquiring additional specialist and soft skills. All parties involved agree that the scientific quality of a doctorate is an absolutely crucial factor in its success. The business and industrial sectors in particular expect and require engineers with doctorates to demonstrate a range of additional skills.

For acatech, the primary concern is not to simply shorten the duration of the doctorate, but to continue to encourage the "best and brightest" to undertake doctoral courses lasting a manageable period of time. These individuals will continue to drive progress in research and technology and thus build the foundations needed to create innovative products that will prove competitive on the international market.

⁵¹ Cf. DFG 1998.

Recommendations

- There should always be a clear, targeted approach to doing and completing a doctorate.
- All those involved in an engineering doctorate should strive to complete the process in under four years.
- The measures listed below are designed to cut back on unnecessarily long doctorates:
 - Restrictions on research, teaching and administrative tasks that are undertaken by doctoral candidates but not directly related to their thesis/doctorate.
 - Regular progress reports to be submitted by doctoral students.
 - Provision of adequate time to work on the thesis and gain specialist and soft skills.
 - Supervisors to share responsibility for ensuring the doctorate is completed quickly.
- In terms of doctoral training, it is important to consider not only the amount of actual working time required, but also the overall duration of the doctoral process. The period between the submission of the thesis and the oral examination should be limited to three months. According to the survey of doctoral degree holders, the average period is currently estimated at six months, while professors put the figure at four months. Any additional work required as a result of the oral examination should be done within three months.
- The examination board and assessors should be appointed prior to the submission of the thesis or at least should be agreed among all the parties involved. This can not only reduce the time taken to organise the thesis defence, but also ensure the thesis submission is not dependent on the schedule of relevant academic bodies (faculty council, doctoral committee).

- Regular colloquiums for doctoral candidates in which they report on and discuss the progress of their work under guidance from professors play an important role in boosting the level of efficiency with which candidates gain knowledge of their specialist field. Participation in such colloquiums should be made mandatory for doctoral candidates and supervisors.
- Doctoral students should also be given the freedom to meet with their peers to report on and discuss their thesis projects without the involvement of a professor.

6.8 PARTICIPATION IN TEACHING ACTIVITIES

Alongside the primary objectives of the engineering doctorate (acquisition of skills and a key contribution to scientific research), involving doctoral candidates in teaching activities has become an integral part of every doctoral project. It is an established tradition at German universities for candidates conducting research as part of their doctorate to provide support to students, whether by supervising undergraduate theses, assisting with teaching, overseeing practical courses/tutorials or providing technical support in laboratories and workshops.

Recommendations

- Involving doctoral candidates in teaching activities is of great benefit not only to the candidates but also to the students they supervise. Teaching experience makes a considerable contribution to doctoral candidates' personal development, helping them to acquire some of the key skills they will be expected to demonstrate in the professional work environment (such as presenting research results and communicating within the international scientific community). Integrating undergraduate students in doctoral projects gives them experience of research at an early stage. The involvement of doctoral

candidates in teaching activities should be neither withdrawn nor reduced.

- Candidates should however be properly prepared for such teaching roles.

6.9 LINKS TO PRACTICAL APPLICATIONS IN INDUSTRY

Engineering is regarded as an applied science. Engineering research has a strong focus on technologies, processes and methods that can be applied in practice and often centres on topics or issues arising in the practical environment. Research projects carried out in cooperation with business and industry frequently form the basis of doctoral projects.

This particularly practice-oriented aspect of engineering is evident in the career paths taken by university teaching staff in this field. After completing their own doctorates, most fulfilled research and management roles in the industrial sector before returning to university activities. The contacts made during their non-university employment generate research and development projects with industrial partners, thus ensuring the practice- and application-oriented approach taken by university research. These often also involve research and development activities commissioned by industrial contractors. In the field of engineering, such work is indispensable when it comes to ensuring the currency of new research projects and inspiring further developments in teaching.

Recommendations

- Cooperation with industrial partners must continue to be an integral part of the engineering doctorate.
- In the widespread context of the research assistant path, the engineering doctorate is much more than a

theory-based qualification for academic professionals. Above all, it is a first step on the career path following the completion of a degree, not an extension or third cycle of the study process as specified by the Bologna Process. The level of independence and the prominent practical aspects applied in research, teaching and project work ensure doctoral candidates develop a comprehensive range of skills, and distinguish German engineering not only from its international counterparts but also from other scientific disciplines. These features are particularly characteristic of the research assistant path and should be neither withdrawn nor reduced.

6.10 INTERNATIONALISATION

With science now increasingly focused on international issues, its international networks are stronger than ever. This applies equally to research in the field of engineering, where research results must be produced with an eye to international competition.

Recommendations

- The engineering doctorate must take into account the growing importance of experience gained abroad, whether that be in relation to the research topic or plans for a career abroad at a later stage.
- Doctoral candidates should publish (partial) results of their thesis in renowned international journals.
- Active participation in conferences abroad or in international conferences held in Germany provides a good opportunity for doctoral candidates to build up and consolidate contacts with scientists based in other countries.
- In addition to boosting specialist knowledge, involvement in international projects also improves language abilities and promotes intercultural skills.

- Doctoral candidates should endeavour to spend a period of time abroad if appropriate to the content of their research topic. This should last around a quarter of a year and take place during the middle phase of the doctorate. By this point, the essential groundwork has already been done but there is still time to put new insights into practice. The higher education institution where the period abroad will be spent and the tasks to be completed during that period should be tailored to the specific requirements of the doctoral candidate and his chosen research topic. There must be regular communication between the doctoral candidate and his supervisor throughout the period abroad. The candidate and his home institution must reach a mutually acceptable agreement concerning payment of travel and accommodation costs and any fees charged by the host university.
- Conscious efforts should also be made to attract foreign graduates to accept research assistant posts or embark on doctoral courses in engineering at universities in Germany. According to the survey of professors, foreign students account for around 15 % of doctorates currently under supervision.
- Welcoming visiting scientists from outside Germany is a particularly good way to promote the international character of an institute or department. Visiting scientists often maintain a lasting relationship with their host university and enrich its work in the scientific field. Professional contacts and exchange visits are an ideal opportunity for doctoral candidates to work on international projects or share in their results.
- International cooperation can also be promoted by two doctoral students from different countries working on the same scientific project (e.g. theoretical and experimental analyses).

6.11 TARGETED SUPPORT FOR WOMEN

In terms of promoting academic professionals in the field of engineering, there continues to be a key focus on ensuring the proper conditions are in place to actively support women in pursuing a career in higher education and in industry. The aim is to establish a personal development structure based on equal opportunities and to make it easier for both men and women to combine a career with having a family.

Recommendations

- Achievable, binding target agreements based on the requirements of the specific disciplines should be concluded between the organisational units and the university management⁵² with the aim of increasing the number of female scientists. As they define only the relevant schedule and scope, target agreements are a suitable tool for this purpose. It is up to partners to decide what methods and measures they use to achieve the agreed targets.
- Methods and measures for increasing the number of women at the various educational levels are allowed to take the form of positive discrimination if the overall proportion of women is less than 30 %. In such cases, advertisements for scholarships and posts should be specifically addressed to female candidates. This covers not only the recruitment of qualified women on a regional and national basis within Germany, but also targeted efforts to attract female scientists from abroad.⁵³
- The proportion of women is significantly higher in courses of study where there is a clear interaction between technical issues and social, economic or ecological problems. As engineering is becoming increasingly interdisciplinary in character with regard to many research and

⁵² Equal opportunities should also constitute part of the target agreements between a university and the relevant federal state.

⁵³ Applied on a temporary basis, "positive discrimination" complies with the General Equal Treatment Act (Allgemeines Gleichbehandlungsgesetz, AGG) introduced in 2006. The Act aims to prevent or eradicate any form of discrimination based on race, ethnic origin, gender, religion or ideology, disability, age or sexual identity (§ 1 AGG). Under the AGG, "positive discrimination" is permissible if suitable and appropriate measures are being used to limit or address existing disadvantages occurring as a result of one of the reasons listed in § 1.

development projects, this aspect of research should be given greater prominence.

- When making career decisions, women are more likely to weigh the appeal of a subject, the scientific challenges and the future employment prospects generated by a doctorate against the given work environment and atmosphere and their own personal circumstances. These factors should be taken into account by those responsible for faculty PR.
- When it comes to deciding on an employer, a family-friendly work environment is a key criterion even for young women who as yet have no family to consider. This also applies to universities and faculties. Consequently, universities and faculties should establish family-friendly structures (flexible working times, childcare options) and select fathers and mothers who manage to combine scientific pursuits with family life as role models. This will boost the appeal of the engineering doctorate to young women.

6.12 TITLE

The doctoral degree awarded for an engineering doctorate at universities in Germany is titled "Doktor-Ingenieur", normally shortened to "Dr.-Ing". This title has a good reputation worldwide and represents the unique character of the German engineering doctorate with its special interaction between research, teaching and project work.

Recommendations

- Universities should continue to award the "Dr.-Ing." title. This complies with the objectives of the Bologna Process, as it is possible to draw comparisons between the academic titles and degrees even without their standardisation. The Bologna Declaration expressly gives member states the option to assert national characteristics as part of the creation of the European Higher Education Area.⁵⁴ This would be the aim of continuing to award the "Dr.-Ing." title for engineering doctorates completed at German universities.
- In the case of doctoral models that represent a third cycle of education as decreed by the Bologna Process rather than a first stage in employment following a course of study, a different academic title should be awarded. As it is already common in the international context, "Ph.D." could be one option here.

⁵⁴ The Bologna Declaration (1999) specifically states that its stipulated objectives should be achieved "taking full respect of the diversity of cultures, languages, national education systems and of University autonomy."

GLOSSARY

In Germany, the process involved in the engineering doctorate is laid down in the doctoral degree regulations of the relevant faculty. The process can vary widely in some respects from university to university. Generally, engineers move through a number of phases within their studies and the doctorate, during which they are given different titles. The key phrases and terms are explained in the following glossary:

Admission to a doctoral course normally requires an appropriate **Diplomabschluss** (equivalent to a Master's degree) from a university or a **Masterabschluss** (Master's degree) from an institute of higher education. The Master's course follows on from the Bachelor's degree. There is a difference between Bachelor's and Master's courses that run consecutively with interrelated content as per the study and examination regulations, and non-consecutive Master's courses that require a Bachelor's degree as a condition of admission, but where the content is not based on the preceding Bachelor's course. There are also other forms of Master's courses that, in addition to a degree, also require no less than one year's practical work experience as a condition of admission. This type of Master's degree is designed to take into account and build on the candidates' professional experience.

Graduates are individuals who have successfully completed one of the named courses of study.

In Germany, engineering doctorates are generally completed within the framework of employment as a **research assistant**, financed by a relevant state office or third-party funding. Research assistants carry out scientific research and teaching activities in an institute or department while working towards their own **doctorate**. Most research assistants are employed for a limited period of time only. This

period of employment can be extended in exceptional circumstances and under the provision of third-party funding.

Research training groups and **graduate schools** offer an alternative to working as a research assistant and are key examples of more structured doctoral training models. Doctoral students receive a scholarship as part of efforts to promote graduate studies and can therefore also be termed **scholarship holders**. They have the opportunity to work in a wide-ranging research environment within the framework of a systematic study programme and to prepare their **doctorate**.

The doctoral process remains the same regardless of whether doctoral candidates work as a research assistant or receive a scholarship.

The **doctorate** is the award of the academic title "Doctor" (from the Latin *docere* "to teach" or *doctus* "taught"). It is the highest academic degree. It is attained by completing a doctorate at a university or equivalent higher education institution with the **right to award doctoral degrees**. In Germany, holders of engineering doctorates are normally titled "Doktor-Ingenieur", shortened to "Dr.-Ing."

Once the doctoral project has been registered with the doctoral committee of the relevant faculty, the research assistant is also known as a **doctoral student** or **doctoral candidate**. Acceptance by the doctoral committee marks the start of the real **doctoral process**.

The doctorate serves as evidence of the ability to carry out in-depth scientific work. It rests on a piece of independent scientific research known as the **thesis** and an oral **doctoral examination** held in public within the university.⁵⁵ The process is deemed to have been completed successfully once

⁵⁵ During the oral doctoral examination, the candidate has to defend their written thesis (Disputation). Doctoral degree regulations in some universities in Germany also call for oral exams in one core subject and one subsidiary subject (Rigorosum).

the doctoral committee has accepted the thesis and the doctoral examination and defence have been passed.

The publication of the thesis marks the conclusion of the doctoral process. The doctoral candidate then receives their **doctoral degree certificate** and the right to use the academic title "Dr.-Ing". Some doctoral degree regulations permit those who have completed the exam but are yet to publish their thesis to use the title "Dr. des." (doctor designatus). In these cases, an appropriate deadline is set for publication of the thesis.

The time required for a doctorate can refer to two different periods. One is the amount of time taken to prepare the thesis itself (**working time**), the other is the overall period between completing an undergraduate degree and completing a doctorate (**duration of doctorate**).

Doctoral projects are usually supervised by a **professor**, but the regulations governing who can supervise doctoral candidates vary from faculty to faculty. Doctoral theses can be supervised by professors, assistant professors or postdocs with a qualification granting entitlement to lecture. This is defined in the respective doctoral degree regulations.

Doctoral degree holders are former doctoral candidates who have successfully completed their examination and received their doctoral degree certificate. The majority work outside the university where they did their doctorate in either the industrial or scientific sectors.

The overall doctoral degree process is laid down in the **doctoral degree regulations** of the relevant faculty.

Generally speaking, the doctorate is part of a strategy to promote and encourage academic professionals. The umbrella term **academic professionals** is used to denote all scientists who are currently in the pre-doctorate phase following completion of their degree, or in the post-doctorate phase. In the first phase, individuals are referred to as research assistants and during the core phase of the doctorate as doctoral students or candidates. Immediately after the doctorate, they move into the postdoctoral phase. Their period as "academic professionals" concludes once they enter a (leadership) position in industry or gain a professorship at an institute of higher education.

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