New challenges for doctoral studies in Europe in the field of electrical and information engineering

Olivier Bonnaud / Michael H.W. Hoffmann

Abstract

The Bologna Ministerial conference in May 2007 was an important step in the evolution of doctoral studies. The EUA analysis undertaken at that time showed that there were big differences in the doctorate in Europe, especially concerning duration, grants and financial supports, duties, complementary classes and seminars. After some general considerations on the main objectives of the doctorate, the article discusses the recent organisation of doctoral studies in France and Germany, with particular reference to the field of electrical and information engineering. The article looks at the skills and competences that are required in order to respond to the needs of the academic and economic world, and addresses the subject of evaluation and accreditation of doctoral studies and schools. Specific examples from the experiences of the authors in France and Germany are used to illustrate the article.

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1. Introduction: the doctorate in the framework of European education policy

The doctorate was mentioned in 2003 for the first time as the third cycle in the now well-known bachelor, master, doctorate structure. These cycles were decided on as part of the overall Bologna process goal to harmonise study structures across Europe and to create the European Higher Education Area (EHEA).

Place of the doctorate

Following the adoption of the European Qualifications Framework (EQF) in 2008, the classification of the doctorate is today much clearer than it was during the early phases of the Bologna process. Indeed, the Bologna process was initially concerned mainly with the two cycles of higher education, undergraduate and graduate, as shown in Fig. C 4.4-4-1 in the cases of both France and Germany. The doctorate was considered as part of the post-graduate phase, as it is still seen (in a way) in the US, and as it is still seen by the Council of Faculties of Engineering and Informatics at German universities (4ING). 4ING considered, and continues to consider the engineering doctorate as the first part of a professional scientific career, though it agrees that the doctorate should lead to a qualification following the European Qualification Framework (EQF), namely the title of a doctor of engineering.

Berlin conference 2003

While the Bologna partners across Europe began to establish bachelor and master studies in the early 2000s, it was not until the European ministerial conference in Berlin in 2003 that the phrase "doctoral studies"[1] was mentioned for the first time, as "the third cycle in the Bologna process", to which access should be given after successful completion of the second cycle. Since then, all levels of higher education, i.e. bachelor, master and doctorate have been covered by the Bologna regulations.[2]

Figure C 4.4-4-1 shows the position of the doctorate in the new scheme for France and Germany: it can begin five years after the completion of secondary school, on average when students are aged 23-24. In many other European countries, the position of the doctorate on a time scale is almost the same. Some specificities remain for engineering studies. In the French system, engineers obtain the master degree and may enter the doctorate. In the German system, only (re-

[1] In Germany, the phrase "doctoral phase" or "doctorate" is preferred, since it is not seen as a study course program like in the first and second cycle.

[2] For a full discussion on the place and development of the doctorate in the Bologna process, please see the following articles in this Handbook: Scott, P. (2007): *The global context of doctoral education*, article C 4.4-1; Chambaz, J., Biaudet, P. and Collonge, S. (2007): *Developing the doctorate*, article C 4.4-2; Bitusikova, S. and Wilson, L. (2008): *Doctoral programmes in Europe*, article C 4.4-3.

search) universities are permitted to award the doctoral degree. Please see the THEIERE thematic network report for more details[3].

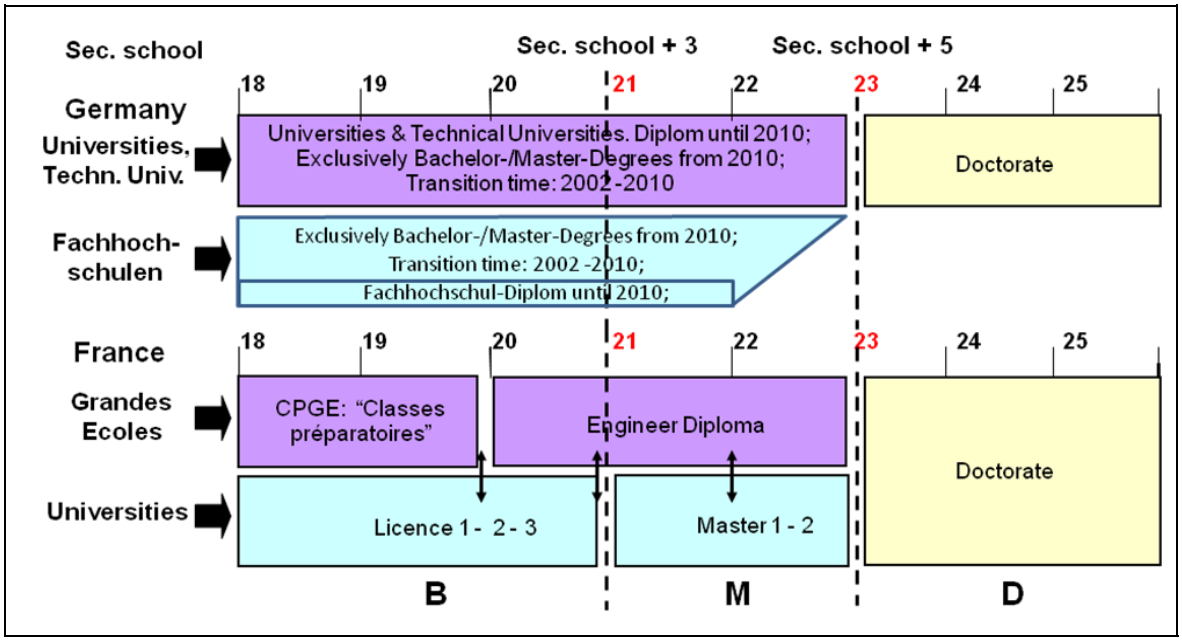

Fig. C 4.4-4-1 Higher education structures in Germany and France

Big differences across Europe

However, an analysis of the situation across European countries, undertaken in preparation for the 2007 ministerial conference in London, showed that there were big differences regarding the doctorate in Europe (EUA 2007), especially concerning duration, grants and financial supports, not only for doctoral candidates but also for related laboratories, and concerning the duties of doctoral candidates, for example complementary classes and seminars that are compulsory in some countries and in others not, or with respect to teaching and supervision obligations. In Germany, universities and industrial associations even do not see the engineering doctorate as part of higher education, but as first part of the professional career, however with a stronger research-oriented profile.

Bergen conference 2005

During the Bergen conference in 2005, European ministers in charge of higher education decided to develop further "the basic principles for doctoral programmes".

[3] M.J. Martins, J.M. Thiriet *et al.* (2003): *Towards the harmonisation of Electrical and Information Engineering Education in Europe*, Thematic Network report, Project Nr. 10063-CP-1-2000-1-PT-ERASMUS-ETNE.

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In France, revised official texts were published by the government in 2006 (Ministry of Education 2006)[4], providing new rules for doctoral studies. Doctoral studies are now organised in doctoral schools, which have new missions and which are evaluated by a national evaluation agency (AERES) with well-defined criteria[5].

London conference 2007

The Bologna follow-up conference in London in May 2007 was a major milestone in the evolution of doctoral programmes. The following quote from the London Communiqué (2007) outlines the strategic importance of doctoral programmes for Europe, and some of the key issues under discussion at the time.

> *"Closer alignment of the EHEA [European Higher Education Area] with the European Research Area [ERA] remains an important objective. We recognise the value of developing and maintaining a wide variety of doctoral programmes linked to the overarching qualifications framework for the EHEA, whilst avoiding overregulation. At the same time, we appreciate that enhancing provision in the third cycle and improving the status, career prospects and funding for early stage researchers are essential preconditions for meeting Europe's objectives of strengthening research capacity and improving the quality and competitiveness of European higher education. We therefore invite our Higher Education Institutions [HEIs] to reinforce their efforts to embed doctoral programmes in institutional strategies and policies, and to develop appropriate career paths and opportunities for doctoral candidates and early stage researchers. We invite EUA to continue to support the sharing of experience among HEIs on the range of innovative doctoral programmes that are emerging across Europe as well as on other crucial issues such as transparent access arrangements, supervision and assessment procedures, the development of transferable skills and ways of enhancing employability. We will look for appropriate opportunities to encourage greater exchange of information on funding and other issues between our Governments as well as with other research funding bodies."*

Electrical and Information Engineering

On the basis of the London Communiqué[6], the following part of this article deals mainly with the specific characteristics of the doctorate in the field of Electrical and Information Engineering (EIE). After some

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[4] Ministry of Education (2006): *Decree of 7th August 2006*, published in the Official Journal of French Republic on 24th August, 2006

[5] For more details, please see http://www.aeres-evaluation.fr/

[6] Conference of European Ministers Responsible for Higher Education, London (2007): http://www.ond.vlaanderen.be/hogeronderwijs/bologna/documents/MDC/London_Communique18May2007.pdf

general considerations on the main objectives of the doctorate, skills and competences are analysed that are required in order to respond to the needs of academia and business world. Emphasis is given to the expected roles of the involved institutions, as for instance research institutions, laboratories, and doctoral schools. Most examples are taken from French and German systems, but many aspects of the reflection come from the analysis of many other countries that have been found by the work performed in Thematic Networks (TNs) that were supported by the European Community, namely THEIERE (Martins, Thiriet *et al.* 2003) and SURVEYOR (http://www.eie-surveyor.org/). Finally, evaluation (and, where applicable, accreditation) of the doctoral phase is considered together with the problem of assessing the competences of doctoral candidates and, later, of the performance of doctors in their professional positions for purposes of quality assurance.

2. Main objectives of the doctorate

Traditional objective

The expected purpose of the doctorate is an important point for analysis. In the early era of "doctoral studies", the main objective was to enable scientists to improve competences and knowledge in science, in order to qualify for academic positions at universities.

19th century changes

A major change was initiated during the industrial revolution in the 19th century, where a distinction between pure and applied sciences became apparent, due to the increased need for improved industrial products, and the need for new production methodologies and techniques. It should be noted that military purposes were also a major motivation for changes in higher education at that time! In the 19th century, for instance, particular educational institutions for engineers were founded in France and in Germany, and special degrees for engineers were created (see for example the history of *Ecole Polytechnique*[7] or a history of engineers[8]). Engineers were then defined in these countries by their education. It might be annotated that at that time some scientists did not recognise engineering education as a scientific education that ought to be made available at a university.

Early 20th century changes

At the beginning of the 20th century, the focus of engineering education changed increasingly to a higher level of skills and competences concerning technical and scientific aspects, which was triggered by the rapid industrial development. This led to a change in the learning

[7] Ecole Pol ytechnique website : http://www.polytechnique.fr/institution/historique_1.php

[8] Kaiser, W, König, W. (2006): *Geschichte des Ingenieurs,* Hanser.

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objectives for engineers. As a consequence, distinctions between different types of institutions of higher education in engineering evolved.

German institutional developments

In Germany, for example, faculties of engineering developed as research institutions, both at classical universities and at distinct universities of technology (*Technische Hochschule, Technische Universität*), and with the clear objective of educating future scientists. In contrast to these, institutions for the education of engineers with highly developed skills in the *application* of engineering sciences evolved from schools, whose teachers were skilled master craftsmen. These schools were called schools of higher technical education (*Höhere Technische Lehranstalt*).

Challenges of increased specialisation

During the last five decades, it has not only been the level of education that has increased considerably, rather, it is also the degree of specialisation. In order to avoid increasing the duration of higher education, different solutions have been found.

German responses

One solution is to keep the knowledge transfer of scientific methodologies to a minimum (which does not mean that the courses are not science based!). This is the way chosen by German *Fachhochschulen*.

Another solution is to put less emphasis on the direct application of learnt methods to everyday needs, but rather to build a rigorous education on scientific methodologies. This is the solution chosen by German universities and universities of technology.

Need for additional studies

It is obvious that in both cases, parts of engineering education have had to be adapted to a period in time after achieving the *Diplom* or *diplôme* or bachelor or master degree. For those engineers leaving institutions of higher education after obtaining such a degree, this is practical experience, training on the job, and any other form of lifelong learning. For those engineers continuing their studies at institutions of higher education, it is the doctorate (and lifelong learning) that might give the opportunity to complete their knowledge.

Anyway, as a consequence, learning objectives have changed to skills and competences that are closer to industrial needs, aiming at the development of transferable skills and promoting interdisciplinary training compatible with applied sciences.

This evolution is shown in Figure C 4.4-4-2. Here, the duration for higher education in basic knowledge areas like humanities, law, or natural sciences is compared to the duration of higher education in applied sciences. Note that, due the increasing complexity of applied sciences as a result of fundamental discoveries, the duration of studies for engineers has increased progressively to reach more or less the same amount of time needed for fundamental studies. Thus, in line with one of the main goals of the Bologna declaration, namely the

adoption of a system of easily readable and comparable degrees, the doctorate has attracted major attention in the further development of the European Higher Education Area.

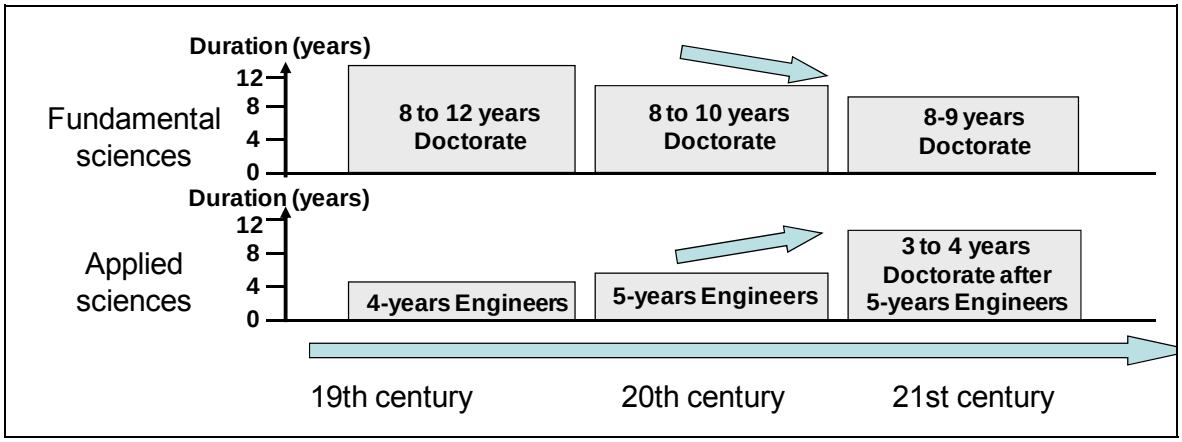

Fig. C 4.4-4-2 Evolution of the doctorate since the beginning of the 19th century

Bergen Communiqué

The Bergen Communiqué (2005)[9] expresses this increased level of attention as follows:

> *"The core component of doctoral training is the advancement of knowledge through original research. Considering the need for structured doctoral programmes and the need for transparent supervision and assessment, we note that the normal workload of the third cycle in most countries would correspond to 3-4 years full time. We urge universities to ensure that their doctoral programmes promote interdisciplinary training and the development of transferable skills, thus meeting the needs of the wider employment market. We need to achieve an overall increase in the numbers of doctoral candidates taking up research careers within the EHEA. We consider participants in third cycle programmes both as students and as early stage researchers."*

Duration of doctorate

The emphasis on duration and on the needs of the market might be best understood when looking at doctorates in the humanities, since the latter have in some cases lasted more than 10 years. In contrast, the duration of doctorates in Electrical and Information Engineering (EIE) is closer to an average of 4 years.

[9] Conference of European Ministers Responsible for Higher Education, Bergen (2005): www.bologna-bergen2005.no/Docs/00-Main_doc/050520_Bergen_Communique.pdf

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As a field of applied sciences, electrical and information engineering lives in an area of overlap between scientific exactness on one side, and practicability on the other side. It must always find a good compromise between research and development. This defines the following competences that a doctor of engineering should acquire, as summarised in Figure C 4.4-4-3:

- the proven ability to use profound knowledge at the most advanced frontier of a highly specialised field, the most advanced personal skills, and methodological abilities required to solve critical problems of this field, and substantial authority, innovation, autonomy, scholarly and professional integrity and sustained commitment to the development of new ideas or processes at the forefront of work or study contexts including research (Hoffmann 2007). In other words, this must be the result of serious and in-depth activities in the field, mainly acquired under the supervision of a professor at an academic research laboratory. This academic laboratory is "the unique environment in which young researchers are trained by and through research" (AERES 2008);
- the proven ability to establish an up-to-date bibliography on a chosen item, to analyse the main results and to extract the main ideas related to innovation in terms of experiments, approach, methodology, etc.;
- the proven autonomy in disclosing new sources of knowledge;
- the proven ability to develop further this knowledge by applying scientific methods;
- the proven ability to manage an own research or development project;
- the proven ability to analyse obtained results critically and to evaluate them in a scientific, creative, and innovative way;
- the ability to work in a team, and in the environment of large facilities, e.g. using large instruments or common experimental platforms;
- the social competence to guide and instruct less qualified members of their team, including definition of work packages, and planning of tasks for those who technically or administratively support the research activities;
- the ability to circulate knowledge in a suitable form to others, mainly by means of the thesis, or by presentations at national and international conferences, and by peer-reviewed publications, thereby enhancing the body of knowledge in their fields of expertise;
- the ability to acquire financial and other means for bringing forward their work.
- The above list of competences is not necessarily specific to doctors of engineering, since it is quite general. It must be completed by sectoral competences.

Handout C 4.4-4-1 Competences required for doctor of engineering

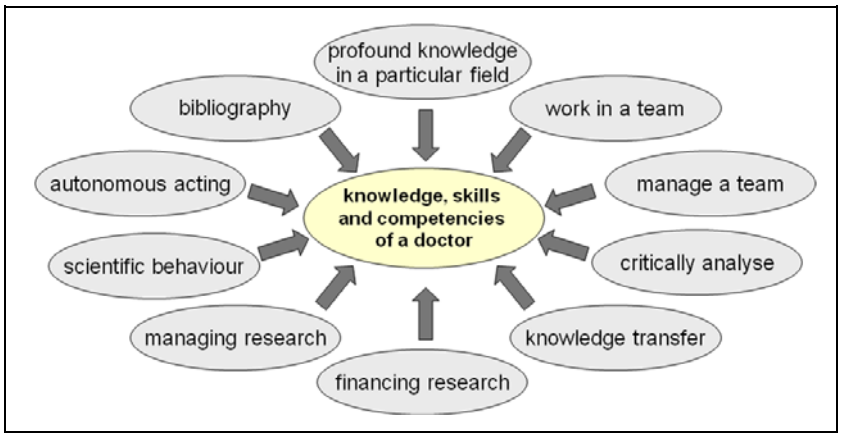

Fig. C 4.4-4-3 **Generic skills and competences any doctor ought to have acquired. These must be complemented by sectoral competences**

3. Organisation of the doctorate

Administrative structures

In following the scheme of the Bologna process, the organisation of the doctorate is supported by an administrative structure. While in Germany the doctoral phase is mainly managed administratively by university faculties (e.g. schools of engineering), in France it is managed by doctoral schools. These are called graduate or post-graduate schools in some countries; some graduate schools exist at German universities also. These schools are frequently shared between several institutions (universities, schools of engineering, etc.), because the attached laboratories are also frequently organised in common. Indeed, depending on the place (larger or smaller city), or on the presence of several institutions with the capability to support local PhD students, the structure may concern several laboratories or research departments across different institutions. The intention is to obtain a relatively light structure for managing and bringing forward the doctoral studies. This allows for a collaborative approach to management and for better mutual use of activities like seminars, winter schools and lectures dedicated to the better preparation of future doctors for the employment market.

French doctoral school structure

Figure C 4.4-4-4 shows a matrix shaped structure of a classical French doctoral school, corresponding to a combination of several research laboratories (or research departments) and several institutions (univer-

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sities or engineer schools). This structure leads to a collaborative approach to many activities at doctoral level.

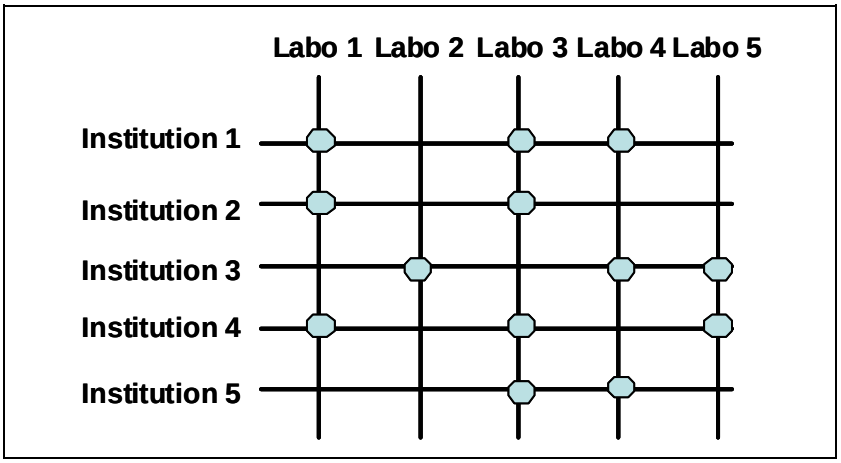

Fig. C 4.4-4-4 Matrix structure of a French doctoral school

Each French doctoral school organises the doctoral education and training of approximately one hundred to five hundred postgraduates. For small universities, all the domains are gathered in the same doctoral school (multidisciplinary school), while in the case of large universities or large areas of academic concentration, several doctoral schools are built based on the main scientific domains (humanities, life sciences and medicine, exact sciences, etc). For example, in the EIE field, the doctoral school MATISSE (http://www.matisse.univ-rennes1.fr) brings together 5 laboratories globally shared between 7 institutions (2 universities and 5 engineering schools), and in 2008 included more than 530 doctoral students.

In 2007, 16 European countries reported that their institutions have introduced doctoral, post-graduate or research schools. In the field of EIE, this evolution is observed in the framework of the Surveyor TN (http://www.eie-surveyor.org/).

4. Organisation of doctoral programmes: important points in EIE

The doctoral phase must be organised in a way that responds to the above mentioned requirements of competences. Figure C 4.4-4-5 summarises the main requirements that must be fulfilled to prepare a doctorate. Several parts are detailed in the following.

Research structures

The first major point is that the doctoral candidate in electrical and information engineering must be integrated into a working research structure. As a general rule, this is a recognised laboratory. This research structure must be able to host the doctoral candidate and to provide him or her with the necessary financial support and technical equipment to perform the required research activities.

Financial support

One way of ensuring private financial covering might be employment of the doctoral candidate as a scientific assistant with a contractual promise to use a certain percentage of time for her/his own research (as it is mostly done at German universities), another way might be awarding grants (which is the most common way in France). These grants may come from governments, regions, the EU, but also research organisations or foundations, research programmes and international cooperation structures, or directly from companies via contracts between laboratories and these companies.

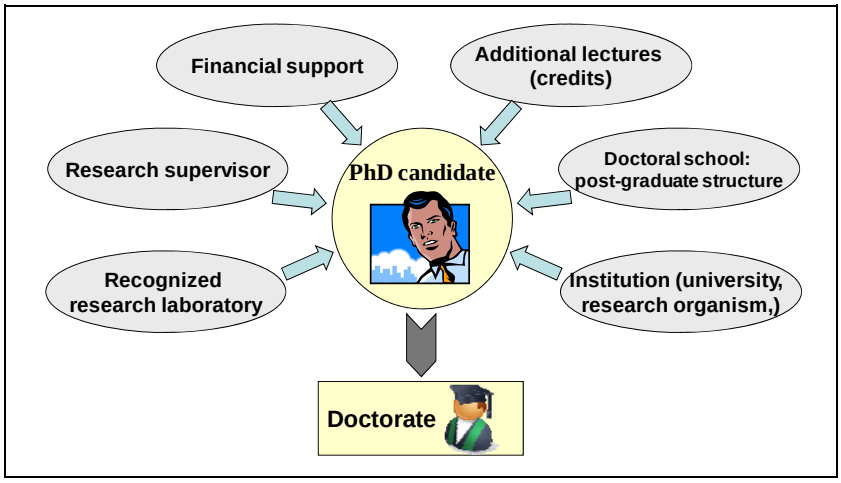

Fig. C 4.4-4-5 Mandatory conditions for preparing a doctorate

During the doctoral phase in electrical and information engineering, the financial support from industry represents a significant part of the laboratory budget, in France as well as in Germany. Figure C 4.4-4-6 provides an overview of where financial resources are obtained in a French doctoral school.

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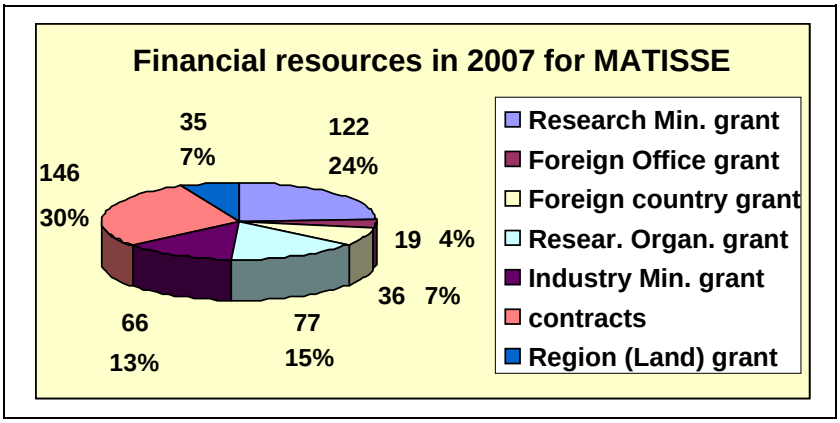

Fig. C 4.4-4-6 **Sources of financial resources resulting in grants or salaries for doctoral students at MATISSE doctoral school (MATISSE 2008)**

In EIE, more than 43 % of the resources are provided by companies, while about one third is given by the French Ministry of Industry. A quarter of the financial resources come directly from the Ministry of Research, and 15 % is funded by research bodies like CNRS, INSERM, INRIA, CEA, etc., or by national or European programmes.

Learning structures

The second point concerns additional lectures, seminars, winter schools, summer schools, etc. that are particularly oriented towards the needs of doctoral candidates. These additional events are gaining increasing importance at many institutions. In order to measure the workload for participating in these events, they can be awarded on a credit basis. The total workload of these events during the doctoral phase can average between 50 to 150 hours, but should not exceed this length in order not to take away from the research work involved.

Reasons for additional learning opportunities

The role of these additional events for doctoral candidates is the following:

- deepening scientific knowledge in a special field of EIE;
- broadening the fields of knowledge in a multidisciplinary approach (mathematics, computer sciences, physics, chemistry, biology, etc.);
- enhancing general knowledge and general skills, for example in foreign languages, management techniques, presentation techniques, human resources management, etc.;
- increasing knowledge in economics and business administration;
- enhancing students' ability to circulate or disseminate scientific knowledge.

The first two points have been part of the traditional responsibility of doctoral candidates in Germany.

Dissemination of results

The last point deals with the valorisation of research results. In other words, the doctoral candidate must demonstrate quality and originality in his or her work by means of publications in relevant peer-reviewed international journals, or by presenting the main results in well-reputed international conferences related to the scientific field.

Patents

Some results need to be protected by patents. The choice between patents and other publications is not at all evident. The supervisor must play an important role here, since this choice may have strategic consequences, not only for the doctoral candidate, but also for the research laboratory.

Basic research and pre-development balance

In EIE, the nature of doctoral work has two different aspects, namely basic research and basic (pre-) development of technical products. A careful balance between both aspects is necessary for the safe existence and survival of the laboratory.

French doctoral school duties

In France, the duties of doctoral schools are to:

- organise admission of doctoral students during the first registration phase, with transparent rules and regulations, thus guaranteeing the quality of the selection;
- check the financial conditions of each student during the three to four years of the doctoral phase, in order to ensure that basic living expenses are covered;
- propose, organise and manage the additional lectures, seminars, etc. and validate the specific training events attended by the student during his or her studies;
- validate the extra activities such as summer/winter schools, scientific seminars;
- monitor the progress of research studies from the thesis commissions or equivalent internal evaluation structure, often specific to the research laboratory;
- encourage some “professional” experiences in terms of teaching or consulting in a company: these must be compatible with a full time researcher position;
- monitor the total duration of the thesis. If the doctoral student is given a grant (which means full time studying), this duration should be at least three years, and not more than four years (on average). The aim of this regulation is to enable doctors of engineer-

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ing to start their professional lives before the age of 30, as preferred by industry;

- validate the defence of the thesis on the base of reports produced by at least two external specialists of the field preferably chosen at international level,
- establish report to the evaluation organisms or to Ministry,
- promote the activities of the doctoral school by sustaining a website, advertising in scientific forum, financially supporting doctorate networks, doctorate seminars and workshops. A target is to attract the best foreign students,
- organise a mediation in case of conflict between the PhD student and the supervisor
- encourage international cooperation and exchanges by the way of several actions: i) mobility grants, ii) thesis co-direction, iii) co-tutorial agreement, iv) involvement of foreign reviewers to evaluate doctoral works and to participate to the defence jury.

Figure C 4.4-4-7 summarises these several points.

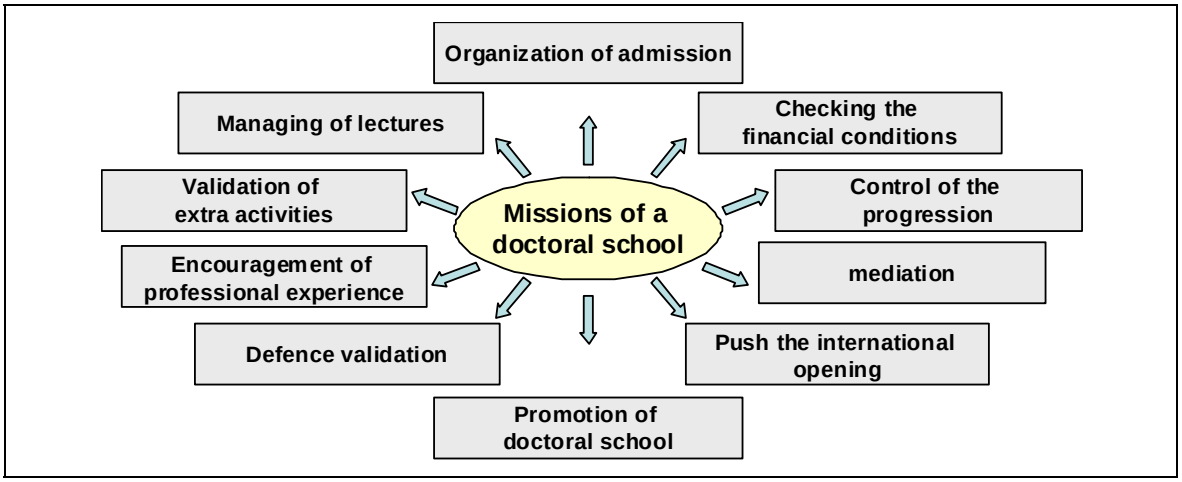

Fig. C 4.4-4-7 **Main missions of French doctoral schools or German post-graduate structures**

German boards for doctoral candidates

At German universities, including German schools of engineering, similar but less formalised tasks are performed by a board responsible for doctoral candidates. The main tasks are to select candidates for

admission, to organise independent, reputed examiners for the doctoral thesis and the doctoral examination, to act as an appeals board in case of complaint, and to perform some other formal aspects. The tasks summarised in Figure C 4.4-4-7 are in the responsibility of the doctoral supervisor and of the board for doctoral candidates at each university/school.

German graduate schools

Where graduate schools exist, another board is in charge for the organisation of lectures, seminars, and other events. There is no admission to the doctorate unless a professor or supervisor has accepted responsibility for the student, and until a field of research has been identified. Likewise, a potential supervisor should only accept a doctoral candidate if the financial resources are available to cover the candidate's work.

5. Evaluation and accreditation of doctoral studies and schools

Maintaining quality

It goes without saying that the quality of doctoral studies must be maintained at a high level. A number of approaches to ensure this are already underway. Examples include the French Agency for the Evaluation of Research and Higher Education (AERES), a governmental structure, and the Council of Faculties of Engineering and Informatics at German universities (4ING), which creates a link between the German schools of engineering and the political world.

Quality criteria used in EIE

Several criteria are used in such an approach. The criteria used in the field of EIE in the case of a French doctoral school are discussed in Bonnaud (2006), and include:

- the reputation, the audience and the scientific output of the research laboratories attached to the doctoral school (quality of the research teams, research staff, visiting researchers and post-doctoral researchers, exhaustive list of publications and conference proceedings;
- the existence of a research policy with priority areas, the distribution of grants and scholarships, a multi-disciplinary approach between or within doctoral schools, support for emerging teams, etc.);
- the relevance and the quality of the thesis topics proposed by the doctoral school;

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- the international policies and the number of jointly supervised theses;
- the average duration of each thesis and the associated research output, including international publications in journals and patents;
- the existence and the application of a code of practice regarding the thesis (specific regulations establishing an agreement between the student, the laboratory, the doctoral school and the institution);
- the pedagogical organisation of seminars and complementary lectures, the relevance and quality of the proposed lectures, the links to the labour market, economics and business, etc.;
- the existence of a research and teaching council, in agreement with the code of practice (with external members coming from business and industry, students, etc.);
- the existence of a monitoring system for tracking PhD graduates after their thesis, and their positions in the research community , in business and industry or in academia;
- the average annual numbers of new doctors compared to the number of registered students; in France the average duration must be between 3 to 4 years in EIE;
- the quality of the transfer towards companies in the research teams.

Handout C 4.4-4-2 Quality criteria used in EIE

Thesis no longer sole criterion

Figure C 4.4-4-8 summarises these points, and shows that the scientific quality of the thesis is not the single criterion used for accreditation, even if this point remains the most important one for the laboratory managers and for their industrial or academic partners. The second main criterion is the employability of the doctor immediately after the thesis. On this point, the EIE field has a significant advantage when compared with other knowledge areas, particularly with humanities.

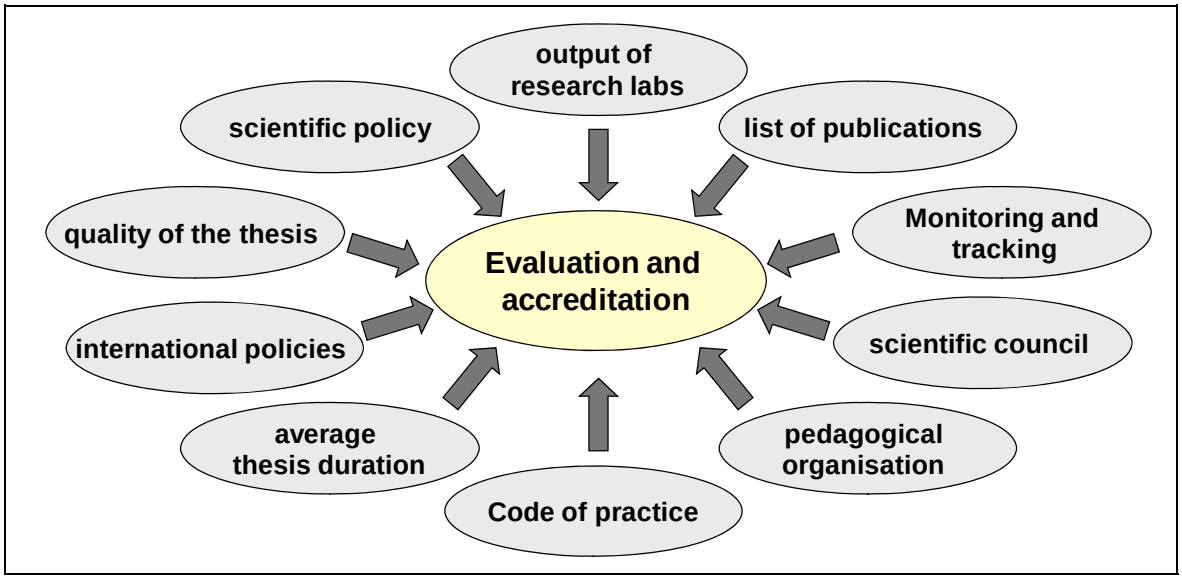

Fig. C 4.4-4-8 Evaluation and accreditation criteria for doctoral schools in France

Accreditation and funding

This rather long list is mandatory for the renewal of accreditation in France. It clearly highlights the increasing importance of doctoral schools in the EHEA. However, German universities have refused to allow the introduction of accreditation of their doctoral programmes. There are, however, two different control mechanisms for these. First of all, the allocation of financial resources by the Federal States and the Federal Government is strongly dependent on criteria similar to those defined above for French research laboratories. The second control mechanism is the need of German schools of engineering to acquire a good part of their finances through third-party funding. These include financial means provided by companies, foundations, and other organisations to perform specific research or development projects. Success in obtaining such funding depends strongly on the reputation of the respective school of engineering, which in turn depends on the quality of doctoral theses. Thus, only high research quality, including doctoral theses, can ensure the survival of the schools of engineering at German universities.

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6. Trends in doctoral studies in EIE

The education of successful engineers working in research and development has become increasingly important for the economic welfare of Europe. The creation of the EHEA is one response to this challenge, through the promotion of higher education at all levels, including the doctorate. In engineering, and more especially in electrical and information engineering, working towards this goal has led to new trends and structures in doctoral education, including the establishment of doctoral schools or equivalent structures, and an increase in the number of doctors who are prepared for the economic and employment needs of the 21st century.

Increased number of doctoral students

As an example, Figure C 4.4-4-9 shows the evolution of the number of doctoral students in the MATISSE doctoral school (MATISSE), and confirms the increased attractiveness of such programmes. However, deeper analysis shows that the increase in number of doctoral candidates is mainly due to an increase of the number of foreign students coming from outside Europe.

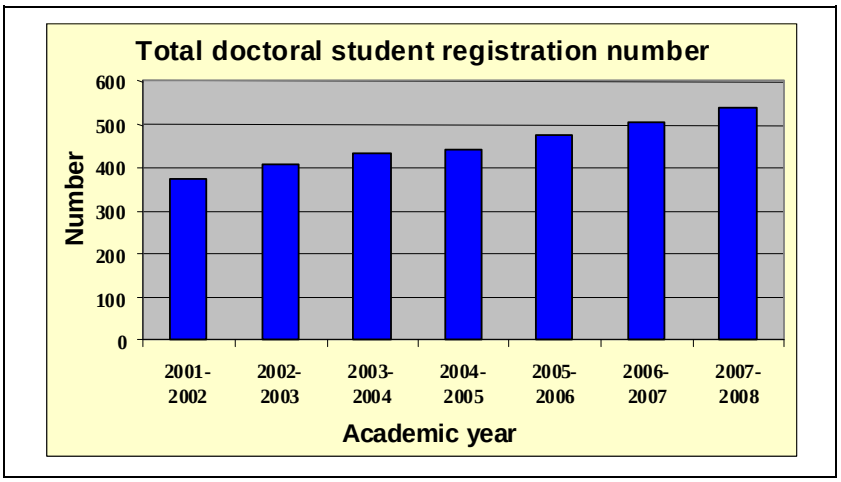

Fig. C 4.4-4-9 **Growth in the number of doctoral students in an EIE doctoral school, 2001-2008**

Growth in non-EU doctoral students

Figure C 4.4-4-10 shows the change in numbers of new doctoral students at the MATISSE doctoral students coming from outside Europe. In 2007, close to two-thirds of all new students were from outside the European Union.

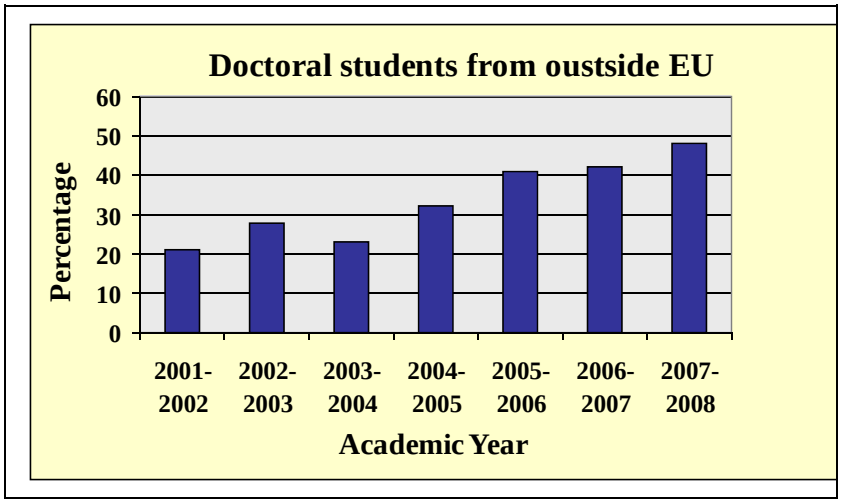

Fig. C 4.4-4-10 **Growth of new doctoral students from outside the EU**

Challenges to attract domestic students

Although this is a positive development for MATISSE, it must also be noted that in the field of EIE the number of European students remains unfortunately almost constant, despite many efforts to attract students in the "exact sciences". It is obvious that much effort is needed across Europe to encourage students in these fields. This explains the change in entry requirements for the engineering doctorate in 2006 by the French ministry (Ministry of Education 2006), in order to increase the number of post-graduates. It has been possible to award the master degree to engineers in France since 2006: these masters can progress to the doctorate directly, if they can demonstrate a minimum of successfully performed, research-oriented courses during the second year of the master. Indeed, Figure C 4.4-4-11 shows the overall decrease since 1995 in the number of graduate students at master level in engineering.

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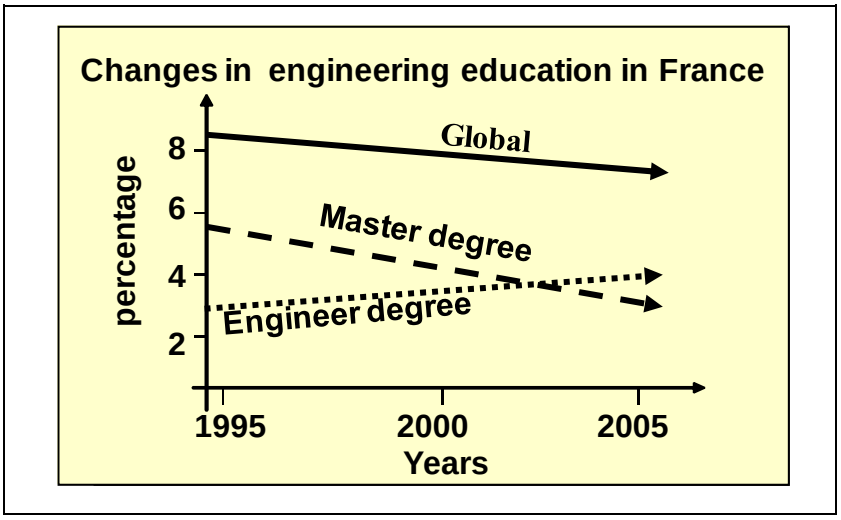

Fig. C 4.4-4-11 **Percentages of French engineering students since 1995 coming from engineering schools and master diploma programmes**

Broader access to engineering in France

While the number of master degrees awarded has decreased dramatically, the number of engineering diplomas awarded has shown a slight increase, due to the creation of many engineering schools in French universities (polytechnic institutes). Motivated students prefer this path, mainly because the course programmes are, pedagogically speaking, more developed, with on average less individual work and with a larger number of lectures, exercises, laboratories and training opportunities. Opening this pathway for engineers was the only way to reduce the catastrophic decrease in the number of PhD candidates, and has meant that the pool of graduate students in France has remained more or less constant. This response has not been the same in other European countries, but creating closer links between the technical and theoretical curricula can provide one response to the need to minimise the overall reduction in engineering students.

New progression routes in Germany

A similar development can be noticed at German universities. While in the old pre-Bologna system, only those candidates were admitted for the doctorate who had a university *Diplom* or who had a *Fachhochschul-Diplom* with additional evidence of knowledge on research methodologies, changes in legislation now require that, in principle, holders of a bachelor degree may be admitted to the doctorate. A bachelor, however, cannot possibly perform tasks comparable to those of a *Diplom-Ingenieur*, whose skills and competences resemble those of a master of science in engineering. For that reason, the costs of doctoral education for these doctoral candidates must be drawn up on a different financial basis. The financial basis for the doctoral education of such candidates has not yet been properly established, let alone

agreed with the funding bodies. It is therefore expected that a good part of these potential doctoral candidates will leave their research institutions in order to work for industry, which is able to pay better salaries.

Demographics

These trends are amplified by demographic developments in Europe. Universities and *Grandes Ecoles* are not able to provide enough fully educated engineers (five years, to master level), since there are not enough students to start such courses. Industry will therefore need to absorb many bachelors of engineering. However, only a small number of bachelors who graduate from universities will come back to continue their studies at a later date. It is expected that this will lead to a further decrease in the number of qualified doctoral candidates.

7. Conclusion

Responding to challenge of Bologna

The examples of very similar developments from France and Germany discussed in this article show that many changes have taken place in the field of EIE doctoral education. Meanwhile, knowledge, skills, and competences define the quality of a doctor of engineering, not only in the scientific or technical fields, but also in interdisciplinary areas. Universities and their schools and laboratories have responded to the new requirements of the Bologna process, and initiated new forms of organisation and new structures to develop the quality of the doctoral phase and to make it more efficient.

Contributing to European competitiveness

It is to be expected that all European partners will be part of this change, and that they will contribute to maintaining and improving the quality of doctors in the fields of engineering, particularly in the field of advanced technology, in order for Europe to remain competitive in a globalised world. A major concern, however, must be expressed regarding the expected numbers of qualified individuals willing to undertake doctoral education in these areas.

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Biographies:

Prof. **Olivier Bonnaud** is professor at University of Rennes 1 and Supelec (Engineering School among the "Grandes Ecoles"). He is director of doctoral studies at the University of Rennes 1, France and director of a doctoral school in the electrical and information engineering field. His main research and teaching activities are in the field of microelectronics technology and devices. Prof. Bonnaud is a member of IEEE, EAEEIE, and the EIE Surveyor Network, a European Thematic Network in the ERASMUS programme.

Prof. **Michael H. W. Hoffmann** works at the institute for microwave techniques at the University of Ulm, Germany. He is chairman of the consortium for the engineering doctorate in the council of faculties of engineering and informatics at German universities (4ING), and president of the council of German university faculties of electrical and information engineering. His main research and teaching activities cover RF and microwave techniques. Prof. Hoffmann is a member of IEEE, EAEEIE, and the EIE Surveyor Network, a European Thematic Network in the ERASMUS programme.

Contact:

olivier.bonnaud@univ-rennes1.fr

Michael.Hoffmann@uni-ulm.de

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