New Trends of Doctoral Studies in Europe: Special Considerations for the Field of Electrical and Information Engineering

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

The doctorate was already mentioned in the early beginning of the Bologna process [1]. The latter was set-up in order to harmonize studies in Europe and to build the European Higher Education Area (EHEA).

During that phase of the Bologna process, the classification of the doctorate was not yet as clear cut as it is nowadays, due to the adoption of the European Qualification Framework (EQF) by the European parliament [11].

Indeed, the Bologna scheme concerned at first only two main cycles of higher education, undergraduate and graduate. The doctorate was considered as part of the graduate cycle, as it is still seen (in a way) in the US.

While the European partners began in the early 2000's to set-up the Bologna process for the bachelor and master studies, it was as late as 2003, when European ministers in charge of higher education mentioned "doctoral studies" for the first time [12], to which access should be given after successful completion of the second cycle, and which was seen from then on as "the third cycle in the Bologna process".

Since then, all levels of higher education, i.e. bachelor level, master level and doctorate (in France comparable to the level of *Doctorat*, in the US comparable to the PhD level, in Germany comparable to the level of a Doktor) are covered by the Bologna regulations.

An analysis of the situation showed that there were big differences in the doctorate in Europe, especially concerning duration, grants and financial supports, not only for doctoral candidates but also for related laboratories, and concerning duties as for example complementary classes and seminars that are compulsory in some countries and in others not, or as another example, with respect to duties as lecturers. 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 with a stronger research oriented profile.

During the Bergen conference in 2005, European ministers in charge for higher education decided to further develop "the basic principles for doctoral programmes" [7].

In France, new official texts were produced by the government in 2006 [2], which gave new rules for the doctoral studies. There, doctoral studies are organized in doctoral schools that have new missions and that are evaluated by a national evaluation agency (AERES [3]) with well-defined criteria.

The Bologna-follow-up conference in London in May 2007 was an important step towards the reflection of the evolution in doctoral studies. From the communiqué of this conference [4], the following text is extracted:

> "*Closer alignment of the EHEA 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*."

The following part of this document deals mainly with the specific characteristics of the doctorate in the field of Electrical and Information Engineering (EIE). After some general considerations on the main objectives of the doctorate, skills and competences are analyzed that are required in order to respond to the needs of the academic and economical world. Emphasis is given to the expected roles of the involved institutions, as for instance laboratories, and doctoral schools. Finally, evaluation (and where applicable accreditation) of the doctoral phase is considered together with the problem of assessing competences of doctoral candidates, and later of the performance of doctors in their professional positions for purposes of quality assurance.

2. The main objectives of doctoral studies

The first point to be analyzed is the expected purpose of doctoral studies. Several centuries ago, in the early era of "doctoral studies", the main objective was to enable scientists to improve competences in science to qualify for academic positions at universities.

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 of improved industrial products, and due to the need of new production methodologies and techniques. It is annotated that also military purposes were 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 [5], or a history of engineers [13]). Engineers were then defined in these countries by their education.

In the 20th century, the focus of engineering education changed more and more to a high level of skills and competences concerning technical aspects, which was triggered by the rapid industrial development. This led to the formation of engineers on a very high level in very specialized fields of interest. During the last decades, this highly specialised knowledge was acquired during the doctoral studies. As a consequence, learning objectives changed to skills and competencies that are closer to industrial needs.

In recent years, the "third cycle of higher education" within the Bologna process has gained much more attention [6]. The Bergen Communiqué [7] that expresses this fact with these words:

> "*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*."

Thus, it definitively emphasises the importance of doctoral studies, and of doctoral programmes. It attempts to limit their mean duration with the aim to meet the needs of the wider employment market.

Electrical and Information Engineering (EIE) as a field of applied sciences lives in an area of conflict 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 competencies that a doctor of engineering should acquire:

- the proven ability to use profound knowledge at the most advanced frontier of a highly specialized field, the most advanced skills and personal, 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 [11]. In other words, this must be the result of serious and deep 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*" [6],
- the proven ability to establish an up-to-date bibliography on a chosen item, to analyze the main results and to extract the main ideas related to innovation in term of experiments, approach, methodology, etc.,
- the proven autonomy in disclosing new sources of knowledge,
- the proven ability to further develop this knowledge by applying scientific methods,
- the proven ability to manage an own research or development project,
- the proven ability to critically analyse obtained results 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 self-contained circulate knowledge in a suitable form to others, mainly by their 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 competencies is not necessarily specific to doctors of engineering, since it is quite general. It must be completed by sectarian competencies.

3. Organization of doctoral studies: important point in EIE

The doctoral phase must be organized in a way that it responds to the above mentioned requirements of competencies.

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 recognized laboratory. This research structure must be able to host the doctoral candidate and to provide her or him with the necessary financial support and technical equipment to perform the required research activities. One way of insuring private financial covering might be employment of the doctoral candidate as a scientific assistant with contractual promise to use a certain percentage of time for 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, lands, regions, EU, but also research organisms or foundations, research programmes, and international cooperation structures or directly from companies via contracts between laboratories and these companies. During the doctoral phase in electrical and information engineering, the financial support from industry represents a significant part of the laboratory budget, as well in France as in Germany.

The second point concerns some additional lectures, seminars, summer-schools, etc. that are particularly oriented at the needs of doctoral candidates. In order to measure the workload for attending these events, they might be awarded by ECTS-credits. The total workload of these events during the doctoral phase might be 50 to 150 hours in the average. It must not exceed this time in order not to put at risk successful research work in EIE. These additional events are gaining increasing importance at some institutions.

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

- deepening scientific knowledge in a special field of EIE;
- opening 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 the ability of circulate or disseminate scientific knowledge.

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

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

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

While in Germany the doctoral phase is administratively mainly managed by university faculties (schools of engineering), it is managed in France by doctoral schools (called graduate schools in some countries; there exist some graduate schools at German universities, also). These schools are frequently common to several institutions (universities, engineer schools, etc.), because the attached laboratories are also frequently common. In 2007, 16 European countries reported that their institutions have introduced doctoral, graduate or research schools [6]. In France, these schools must:

- organise admission of the doctoral students at the first registration with transparent rules and regulations, and thus guarantee the quality of the selection,
- check the financial conditions, in which the student will be during the three to four years of the doctoral phase; a guarantee to insure the basic life expanses is required,

- suggest, organize and manage the additional lectures, seminars, etc. and validate the specific formations attended by the student during her or his studies,
- validate the extra activities such as summer/winter schools, scientific seminars,
- control the progress of the research studies from the thesis commissions or equivalent internal evaluation structure, often proper to the research laboratory,
- encourage some “professional” experiences in terms of teaching or consulting in company that must be compatible with a full time researcher position,
- take care of 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 (in average). The aim of this regulation is to enable doctors of engineering to start professional life before the age of 30, which is 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 forums, financially supporting doctorate networks, doctorate seminars and workshops. A target is to attract the best foreign students,
- 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 defense jury.

At German universities, similar, but not so strongly formalised tasks are performed by a board in charge 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 appealing instance in case of complaint, and to perform some other formal aspects.

Where graduate schools exist, another board is in charge for the organisation of lectures, seminars, and other events. There is no admission for the doctorate without acceptance by a professor as a supervisor, or without a given field of research. It is in the responsibility of a potential supervisor to not accept a doctoral candidate, if there is no financial covering of the work.

4. Evaluation and accreditation of doctoral studies and schools

It goes without saying that the quality of the doctoral phase must be held at a high level. Several approaches to solve that problem are already in effect. Let us mention the French AERES agency, a governmental structure [3], or the council of faculties of engineering and informatics at German universities (4ING) [8-9], which creates a link between the German schools of engineering and politics.

Several criteria are used for this approach. A previous paper was devoted to the presentation of these criteria in the field of EIE in the case of a French doctoral school [10]. These criteria are mainly:

- the reputation, the audience and the scientific outputs of the research laboratories attached to the doctoral school (quality of the research teams, research staff, researcher visitors, and post-doctoral searchers, exhaustive list of publications and conference proceedings),

- the existence of a scientific policy about the priority of the disciplinary fields, the choice of the grant fields, multi-disciplinary approach inter or infra doctoral schools, accompanying of the emergent teams, etc.),
- the relevance and the quality of the thesis subjects proposed by the doctoral school,
- the international policies and the number of co-tutorial theses,
- the average duration of each thesis and the associated scientific production that includes first of all international publications in journals and patents,
- the existence and the application of thesis chart (specific regulation establishing an agreement between the student, the laboratory, the doctoral school and the institution),
- the pedagogical organisation of seminars and complementary lectures, the originality and the quality of the proposed lectures, professional approach, economical learning, etc,
- the existence of a scientific and pedagogical council in agreement with the regulation (external members coming from socio-economical world, students, etc.),
- the existence of an observatory having in charge the analysis of evolution of the doctors after their thesis, that means the professional position of the doctors in the research community, in the companies or in academic world,
- the average annual flux of new doctors in regard with the number of registered students; the average duration must be between 3 to 4 years in France in EIE,
- the quality of the transfer towards companies in the research teams.

This rather long list (including several annexes) is mandatory for renewal of accreditation in France. It clearly highlights the increasing importance of the doctorate schools in the EHEA.

German universities resist accreditation of their doctoral programmes. There are, however, two different control mechanisms. First of all, allocation of financial means by the states and the federation depends strongly 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 by so-called third-party funds. These are financial means given by companies, foundations, and other organisations to perform specific research or pre-development projects. The success in procurement of these funds is strongly based on the reputation of the respective school of engineering, which on its part depends on the quality of doctoral theses. Thus, only high quality of research including doctoral theses ensures survival of the schools of engineering at German universities.

5. Conclusion

The education of successfully working engineers in research and development is more and more important for the economic welfare of Europe. Its response to this challenge is the creation of the European Higher Education Area, and in particular the advancement of higher education on all levels, including the doctorate. In engineering, and in particular in electrical and information engineering, achievement of this goal has led to new trends and structures in doctoral education.

The example of very similar developments in France and in Germany shows that a change has taken place. Meanwhile, knowledge, skills, and competencies define the quality of a doctor of engineering, not only on scientific or technical sectors, but also in interdisciplinary areas. Universities and their schools and laboratories have reacted to the new requirements. They have initiated organisations and structures to control the quality of the doctoral phase and to make it more efficient.

It is to be expected that all European partners will be part of this change, and that they will contribute to maintain and to improve the quality of doctors in the fields of engineering, particularly in the field of “High Technology", in order to stay competitive in a globalized world.

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