Informatics Doctorates in Europe

Some Facts and Figures

Manfred Nagl

Executive Summary

This report describes the findings and conclusions of an investigation, carried out for the ECSS 2012, Summit of Informatics Europe in Barcelona, where the quality of Informatics doctorates in Europe was discussed. For this investigation a simple approach was used: experienced colleagues from different European countries reported about their experience by filling in a questionnaire. The investigation is based on an analysis of these questionnaires.

There proves to be considerable similarity for the doctoral process: the candidate, by 85% chance a male and 80 % from the home university, is in the average 29 years old and has used 4.5 years for the dissertation.

The doctoral dissertation has a mean length of 200 pages and is mostly a monograph. It is becoming more and more a standard that the thesis is written in English (at the moment 70 %). Most results of the thesis have been published in the form of 5 to 10 articles in proceedings and journals before thesis submission, and they are written completely in English.

The scientific competences of a young doctor are comparable throughout Europe: from creating results (new ideas and solutions), discussing their underlying ideas and advantages (writing, presenting, and defending) to networking (creating contacts and cooperating).

Many procedural differences exist in different departments, due to different habits and traditions in universities and different countries of Europe, mostly at the beginning and end of the doctoral process. The doctoral process looks similar only on an abstract level. The essentials of a doctorate (ambitious candidate, supervisor obliged to scientific measures, faculty looking for quality) are not touched by the various differences.

Several dimensions for a characterization of the doctorate were found. Also 3 typical models are described: the Anglo-American model, the Northern European model, and the Central European model. Many doctorates in Europe consist of a mixture of these models.

The context, in which the doctoral process is carried out, plays an important role, less for the scientific competences but for further competences. If the position of the candidate demands for further duties (education, project work, technology transfer to industrial partners etc.), eventually accompanied by an application-oriented research topic, then further competences result. Industry appreciates that kind of doctoral qualification in some countries of Europe. In most countries scientific competences alone only help for an academic career.

As the scientific qualifications can be achieved by any of the models in use and the essentials of the doctoral process (and also further qualifications) are not due to regulations, we see no reason to look for a new and unified doctoral model in Europe. Looking how it works in different universities and countries might detect some habits which could be used elsewhere, if compatible to the local conditions.

Informatics Doctorates in Europe – Some Facts and Figures

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Abstract

This report describes the results of an investigation about the different forms of the Informatics doctorate[1], which has been carried out for the ECSS 2012 Summit of Informatics Europe in Barcelona. After a motivation in section 1, we first describe the simple investigation method used in section 2. Then, we give in section 3 a characterization of the Dissertation process and in section 4 also of its two results, the thesis and publications on the one hand and the profile of the person holding the doctorate on the other hand. In the following section 5, we extract some answers which were given to the question "What makes Informatics research?". The conclusions are drawn in the following two sections. In section 6 we characterize the main models found in Europe and emphasize how similar or different the doctorate in Europe really is. Section 7 gives two more political conclusions, namely about the importance of doctorates to industry and whether we need a unification to one standard model in Europe, or whether we should preserve the variations, currently available. So, sections 3 to 5 deliver the findings of our investigation, whereas the next two sections 6 and 7 evaluate these findings and give the conclusions we have drawn.

Keywords: *Dissertation in Informatics, variety in Europe, parameters for the Doctoral process, Doctoral Thesis, profile and competences of the Doctor, characterization of Informatics research*

1 Introduction and Motivation

We know that there are *different university structures* in the world. Well-known is the model of the *private elite* university from the United States, like Harvard, MIT etc. Also known - by name, not necessarily by its internal structure - is the British *College* University, as Cambridge or Oxford. From France we have heard about the *Grandes Ecoles*. A big influence on university development was assigned to the *Humboldt model* from Germany, uniting research and teaching. Back in history, we have to mention the *prototype* of universities coming up in Italy around 1200, as e.g. in Bologna. Historically interesting are the various *predecessors* of universities of the medieval time and before.

We also know that there are *tremendous differences between the cultures* of *different disciplines* how to make research or science and, therefore, also for their doctorates. Corresponding to the dimension *preciseness* an interval is spanned e.g. from Arts to Mathematics, with respect to *constructiveness* from liberal arts to engineering, and corresponding to *duration/effort* of the Doctoral process from Medicine to Engineering or Natural Sciences. Further dimensions exist, like natural language expressiveness, suitability for a profession, specialization vs. generality, etc. So, investigations on doctorates over all

[1] The title PhD is often used in the English or American language. However, it characterizes a specific way to get the Doctorate, as we shall see. That is why we speak more neutrally about Doctorate in this report.

disciplines (as [Ha 12, Ja 12]) are of limited value. On the other hand, some rules of good behavior can be defined, being independent of any doctoral culture [pnn 11].

We normally assume that *within one domain* - like Informatics in this paper - the situation (culture and quality) is rather *similar*, not only between universities of one country but also *across countries*. But is that really true? A partial verification or falsification of this assumption is aimed at by this paper, by looking at Informatics doctorates in different European countries.

The *investigation* described here was triggered by *Informatics Europe*. The annual ECSS Summit of 2012, located in Barcelona, had the key topic "What makes a good PhD?". We wanted to know the state of the art for Doctoral dissertations in Informatics, in order to discuss the differences across Europe at the ECSS 2012, or to be prepared for making improvement suggestions. Therefore, the investigation described in this paper was started, and its results were presented at the meeting.

It should be mentioned, although being known, that the *doctorate* has a huge *influence on the scientific output*. Most of the publications originate from preliminary or final results having been achieved in the Doctoral phase. These publications are main contributions to the outside visibility of a department or faculty. So, Doctoral dissertations are a good and also important indicator for the character of a discipline. Therefore, it is worth to study the specific Doctoral phase when wanting to know something about the research of a discipline, as here Informatics.

2 The Investigation and its Simple Method

A simple *method* was chosen in order to keep the effort of the investigation manageable. *Experienced professors*, selected in all European countries - who have regularly been engaged in Doctoral Dissertation procedures in the past and do not only know the situation in their universities but also in the whole country - were asked to *report* about their *experience*. The number of colleagues, asked for reporting about their experience, was tried to be in balance to the size of the country and its number of Doctoral Dissertations. Furthermore, we also tried to cover the situation in a country by asking colleagues of big and small universities, of classical universities or technical universities/ institutes of technology, of labs, academies, etc.

In order to get these experience data we worked out a *questionnaire*[2]. This questionnaire was sent to 86 experienced colleagues of 28 countries, 2 to 5 per country, depending roughly on the number of doctorates per year. The questionnaire needed about one hour to be filled in. We got 68 *answers*, a remarkably high reply rate of about 79%. This high rate is due to the fact that the investigation is specific to a discipline, the colleagues regarded it to be useful and, therefore, contributed to get a reasonable result.

The replies are not complete, but compose a *good coverage* of Europe, see fig. 1. At least all countries[3] of Informatics Europe are represented. A dark bubble means that we got an answer from an institution at this place, a light bubble indicates that we got an answer from somewhere else, also being valid for the institution of this location. In some cases (northern Italy, The Netherlands) we even got more

[2] By Uli Heiß, Jan van Leeuwen, and the author

[3] i.e. a country, where Informatics Europe has at least one member

answers than expected, as the replying colleagues sent the questionnaire to other colleagues, who also replied. In this more general sense, we even received 76 answers.

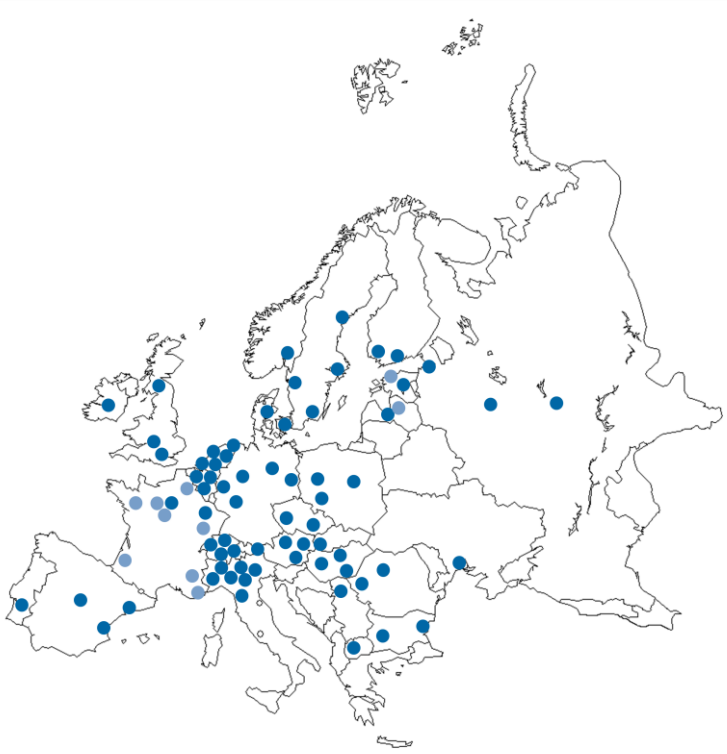

Fig. 1 Coverage: from where we got answers

The immediate *consequence* were 2 *folders* (c.f. fig 2.a) containing 500 to 1000 mails and questionnaires. In some cases we had to remind several times, in other cases, the filled-in questionnaires implied further questions, further replying mails were sent, etc. The main results of all answers were put into a large *Excel sheet*, see fig. 2.b. The results of the investigation were presented at the ECSS 2012 in November. This report gives a *written description* in order to facilitate the distribution of the results. Altogether, the investigation demanded an overall effort of about 4 to 5 person months, which is quite low for an investigation of this kind.

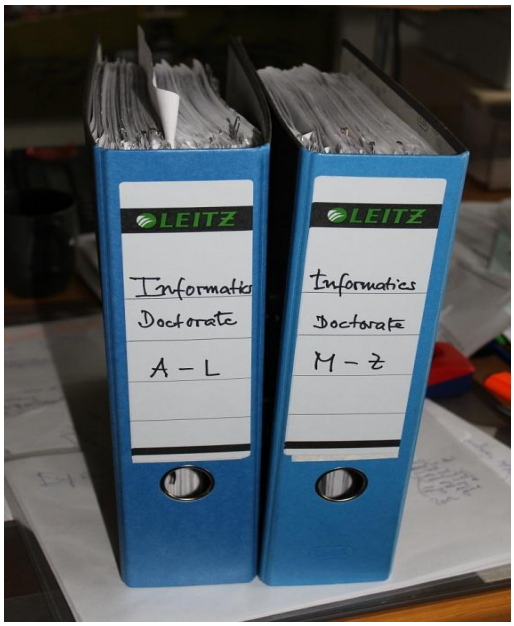

Fig. 2.a Emails and filled-in questionnaires

Fig. 2.b Excel sheet for facts' bookkeeping

3 Characterization of the Doctoral Dissertation Process

In this section we give a view on the Dissertation process in Informatics from three different viewpoints: outside parameters, internal structure, and general aspects. For a general discussion about doctoral education in Europe, see [EUA 05a, 05b, 09]. The following statistics are not given for each country but combined over all countries. However, we watched the variation within each country and the variation from country to country.

3.1 Parameters of the Doctoral Dissertation Process

Fig. 3 gives the *distribution* of the *duration* of the dissertation process *in years*, from its beginning to its successful end: the *mean value* is 4.62 and the *median* is 4.5 years. A number, like 4.5 says that either 4.5

was given as the answer, or the answer was the range from 4 to 5 years. Durations like 4.75 always indicate a specified range, here from 4.5 to 5, as there was no answer 4.75 given in a questionnaire. We see that the main part is between 3.5 and 5. Below 3.5 there is a special situation (strict student model, see below). Above of 5 years we find special cases (like (a) a thesis is continued after the university period and finished during work life, or that (b) the dissertation is produced in parallel to work time, or (c) family situations (mostly children's education) require part-time solutions, see another investigation [Na 11a]). All these nonstandard ways to get a doctorate are valuable and, therefore, should not be cut off. They, however, demand for a longer duration. In many answers, where the duration deviates from the official time span, the answer was like "6, officially 4". In these cases, a reference was mostly given to a difficult economic situation, obligation to work in parallel, part-time doctorate, etc.

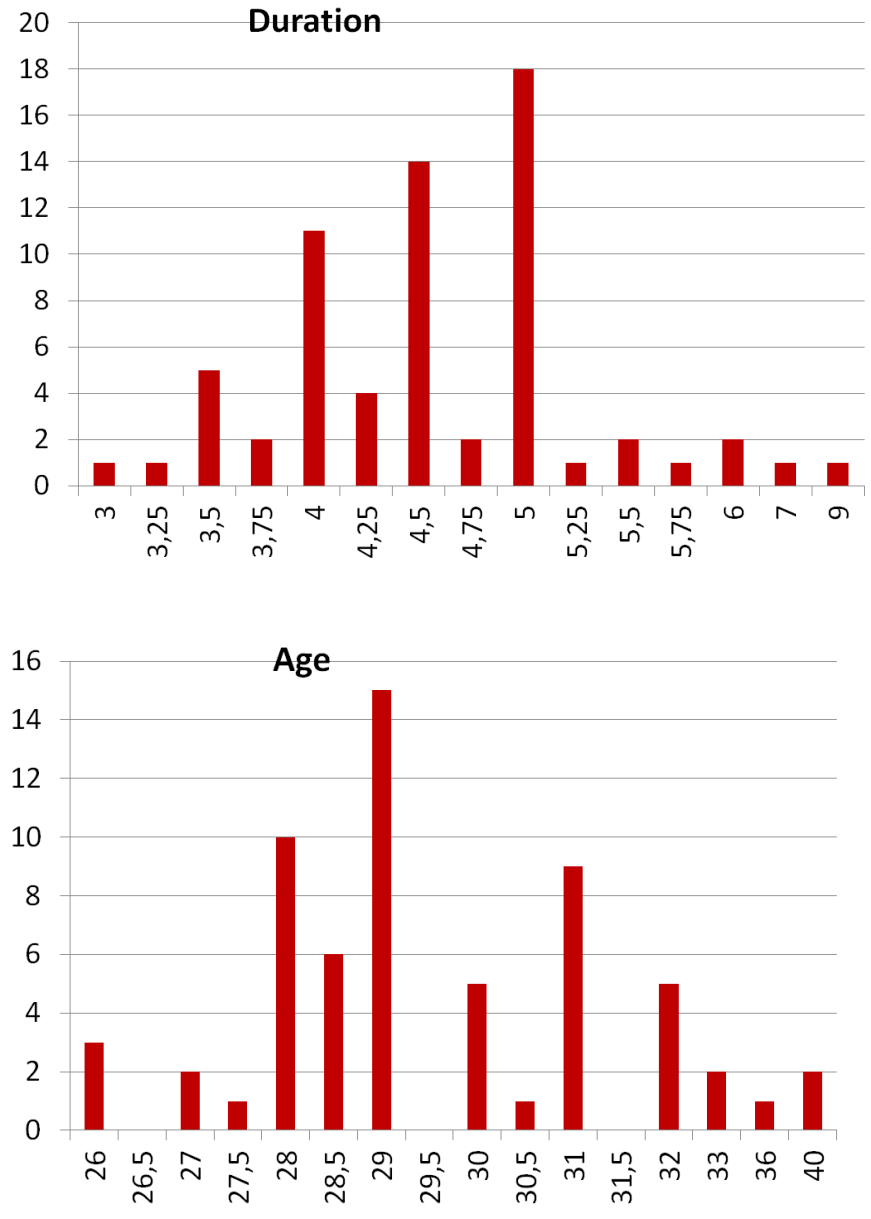

Fig. 3 Duration and age distribution for finishing a doctorate in Informatics

The second question to be answered was the *age* when finishing the doctorate, see again fig. 3. The distribution is from 26 to 40, the major part *between 28 and 32*. The *mean value* is 29.8, the median 29 years. The cases below of 28 are rare and above of 32 are a minority. They have the same characterization as given for the border cases of duration of the last paragraph. In the case of an answer with a number above 33 a special explanation was mostly given, like many candidates[4] make their doctorate as part-time activity.

The women *percentage* ranges from 5 to 40%, both being very extreme situations. In most cases the percentage is surprisingly quite *constant around 15%*. The percentage of *foreigners* from other European countries or from all over the world is from 0 to 70 %. Both are very rare cases ((a) bad economic situation which does not allow to give any funding, a complicated language must be learnt as one extreme; (b) a well-known and rich university at an attractive location gets many more foreigners than other universities). The main part of the answers is *around 20%* or small variations thereof.

Very interesting is the *percentage* of students *going for the PhD*. The range is from 5 to 30%, in most cases - and again surprisingly constant - the *percentage varies around 15%*. So, less than 1/6 of the students are getting a chance to go for a doctorate or are willing to do it.

The *entrance qualification* in most countries is a *Master* degree. In Anglo-American states or states being influenced by the corresponding dissertation culture, the PhD process can start with a *Bachelor* degree. In some locations some Master courses have to be successfully passed and English language expertise has to be shown in order to get into the program. Later on, some intermediate exam is made, roughly comparable with a Master[5]. However, as there is some competition to get a chance for the PhD (1/6, see above), the selection evidently prefers Masters. So, the dominant situation in Europe is that the entrance qualification for the doctorate is the Master.

Summing up, the "typical" doctor has spent about 4.5 years for the degree, is about 29 years old, has usually started with a Master, has an 85% chance of being male, and about 80% from the home university or country. These all are average values, which do not describe the individual situation and do not express a future or even a wanted situation (e.g. regarding the minority of women).

3.2 The Structure of the Doctoral Process

The *process in five steps* is given by fig. 4. We find (1) an entrance phase (which we call recruiting), (5) a finalization phase defence and three steps in between: (2) getting started, (3) on safe ground, and (4) approaching the final goal. These five steps will be discussed now. All these steps are handled more or less formalized or informal. There are very different traditions in faculties/ universities. In most cases these traditions are similar for all universities of a country[6]. At the successful end of the Doctoral process a title is awarded, which can have quite different names.

[4] In this paper we prefer the term Doctoral or PhD *candidate* instead of Doctoral or PhD *student*. The reason is that in some countries, the status of a person aiming at a Doctorate is that of an employee and not of a student.

[5] In the US often called PhD candidacy exam

[6] The only counterexample, we recognized, was Switzerland, where the French, Italian, and German speaking parts follow different habits.

Fig. 4 The process in 5 rough steps

The *first phase Recruiting* (1) of new students/ candidates may have quite different forms: (a) Who is hiring and how is hiring processed: This can range (i) from an informal interview of a group leader, who has acquired money for a project and decides immediately, to (ii) a written exam, followed by interviews done by a small committee, suggestion for hiring decided by another committee, and the decision being formally approved by a dean and/or leader of a Doctoral school etc. (b) Hiring dates: This may be done on the occasion of an open position, or at few and announced dates. (c) Competition: In any case there is a selection (on the average 1/6 of all students get a chance or want this chance). Depending on the attractiveness of the location and the number of applicants, the selection may be more or less tough. In many answers we found the statement, that most of the Doctoral students/candidates are from the own faculty, on the one hand because they are best known from a Master/ Bachelor Thesis having been done before, and on the other hand because the number of applicants from outside is limited. (d) Formal handling of the following Doctoral process: Right at the beginning, the formalities of the Doctoral process are agreed upon; this is usually not depending on individual negotiations but on the traditions of the location. The kind of supervision, mentoring, the salary, the fees etc. are determined[7].

The next *phase Getting Started* (2) is also characterized by different aspects: (a) The study program (PhD curriculum), which is more or less extended, ranging from 10 to 90 ETCS credit points. The biggest part is for lectures in the area of specialization; in some locations also lectures for soft skills are included or demanded. (b) In this phase also the literature, which is the basis for the research, is studied. (c) Usually, after one year the first ideas about the topic and the goals of the thesis should have been developed. (d) After one year there is usually an official or an unofficial Go/ NoGo decision.[8]

In the following *phase On Solid Ground* (3), which is usually finished after two or three years, (a) the topic of the thesis is fixed and also how the goal is approached. (b) Typically, the table of contents in some rough form is determined. (c) This phase might again include some Go/ NoGo decision and a formal approval.[9]

Surprisingly, there are no rules and constraints for the following main *phase Getting it Done* (4): (a) In this phase the research is in full swing, most of the intermediate results are presented at workshops/conferences to the scientific community, and are published in proceedings and journals. (b) This happens with a regular discussion in the group, which already started in the two preceding phases, at least with the last one. (c) In many cases, different dissertations are worked out within the group, in the doctoral school, or in a big project. So, a candidate usually has different partners for discussions.

[7] For example, in Scandinavian countries it is mostly not allowed to hire a candidate, if the salary is not clear and provided for the whole doctoral process.
[8] In the UK after one year there is a formal step, in the case of success called “Transfer” or “Upgrade”. Please remember, that in the UK the official entrance degree is the Bachelor.
[9] In Sweden, after the formal approval, the academic title Licentiate is awarded.

The most complex *phase* – regarding rules, traditions, and habits - is the last one, *Finalisation* (5). We are going to split the explanation into two parts.

After Thesis submission there are two models: (a1) The thesis is sent to reviewers - who write a formal statement of about 3 to 5 pages about the thesis, which later has an important role in finding the final grade. Alternatively, (a2) the thesis is sent to opponents, who write down questions or questioning comments about parts of the thesis. The latter model is used in the UK, in Scandinavia, in parts of the Netherlands, the first in most of the other parts of Europe[10]. (b) Then, the formal decision on formally accepting the thesis is taken[11]. This decision can be made in connection to some official exam, called predefence.[12]

The *Examination/ Defense* often contains – as part of the exam, or done before and not officially belonging to the exam – (c) a presentation of the main results given by the candidate. (d) In the case of the opponent model, the candidate has officially to reply on the comments and questions of the opponents, and the reply is again a topic of discussion. In any case, (e) there are critical questions and discussions with the candidate, about the thesis, the approach taken, about alternatives, extensions, and alike. The discussion is to show that the candidate is now a scientific peer. (f) The doctoral exam can also contain a question and answer part about the specific area in which the dissertation was written, or even about other areas of Informatics or Informatics in general, as in other exams. (g) The Doctoral exam in different countries can take one hour up to several hours. (h) The Doctoral commission after the exam decides about success or failure, the latter being quite rare, and about the grade, if grades are given. This decision in many places is afterwards formally approved.[13]

The most *active person in supporting* the doctoral process is the *supervisor*.[14] There might be a second supervisor, or additional advisors and mentors. The supervisor is usually the leader of the group in which the Doctoral dissertation project is carried out. As research relies more and more on finding external financial sources, the supervisor is often responsible for applying for a research project, which delivers the financial basis of the Doctoral dissertation project.

As doctors should be prepared for leading positions later in their life, a key topic of *support and guidance* is that it *leads to independence*. Guidance might be closer at the beginning of the Doctoral process and is incrementally loosened during the process. An example is that the first paper is written together with the supervisor, whereas later papers may be written by the candidate alone. Another example is that at

[10] These different models also apply later to the examination/ defence. There are also cases in between the two models. The real difference is whether the reviewers mainly determine the acceptance and grade of the thesis, or whether this is done by the whole Doctoral committee. In the opponent model, the supervisor is not allowed to write a review and he is – at least officially – not in any way engaged in the decision or finding the grade. The opponent model is often combined with cumulative dissertations, see below.

[11] This formal decision is often taken as first part of the examination, see next paragraph.

[12] In some universities, the predefence is the important exam; the defence afterwards is only a ceremonial certification of this decision.

[13] By the Dean, the university Vice President, etc. In Russia, there is a nationwide commission, which finally decides about success/ failure of all dissertations, after all the decisions have been made by the local university. There, we also find a specific habit: Every thesis, after thesis submission, is sent to a reference university (one of the big and known universities). If that reference university does not accept the thesis, the whole procedure at the local university is stopped.

[14] It is quite interesting that there are different names for this role: supervisor, advisor, mentor, directeur de thèse, doctor father/ mother. Looking carefully, these names also reflect different attitudes and traditions.

the beginning there are regular meetings, whereas later discussions are on the basis of problems occurring and on the level of discussions with a peer scientist.

The role of supervisor in the final phase is different. Whereas in most countries the supervisor also plays an important role in the in the final phase, in the UK, in Scandinavia, and also in some universities of other countries the *supervisor is not a part*[15] of the *examination process*. This model is usually combined with the opponent model, but we find it also in combination with the reviewer model.

We have learnt that there are different *intermediate stages* in the Doctoral process, often *combined with a Go or NoGo decision*: This appears the first time in the recruiting phase, after the first year (getting started), after the second/third (on solid ground), after thesis submission and in the defence. Of course, this can also happen in between, e.g. in the getting done phase if no further results are achieved due to a changed personal or financial situation.

The *title awarded* with the doctorate is *different*. It can vary per country and even per faculty. In those countries following the Anglo-American model, it is the PhD. Many questionnaires just named it PhD, because the local name is not known outside. In many cases we find a Dr. of Natural Sciences, a Dr. of Science, and even a Dr. of Computer or of Computing Science. Quite often, a Dr. of Engineering Science (Dr. Engg., Dr. Ing., Dr. tech., Tekn. D.) is given. Names are derived from Latin (like Dr. rer. nat.) or from national languages (Dottore di Ricerca, here from Italian). Please be aware that the title is often bound to the specific faculty. For more or less the same thesis a candidate can get a different title, depending on the faculty he/she is graduating from. In Russia and Ukraine we find the doctoral title "Candidate of Science".

In about 40% of the locations, no *grades* are given, only passed or failed is determined and officially reported. In some places, passed can be attributed by "with distinction". Quite often 3 or even more grades are given, often in Latin (as summa cum laude, magna cum laude, cum laude, etc), in natural language, or in numbers. There seems to be an unofficial agreement that the best grade (with distinction, summa, or else) is only given for about 5 to 15% of all successful completions.

The doctoral process in an abstract form looks *similar in most countries*. However, as shown above, we find a huge number of *procedural and formal varieties*, especially in the recruiting, in the getting started, and in the finalization phase. Also, but not being discussed above, the procedure in a certain context can be regarded either as an academic examination with different steps beforehand or – especially in the finalization – more as an academic ceremony.

3.3 General Aspects

The whole doctoral process after recruiting starts with an initial – and rough – *plan* and a corresponding *agreement* between the candidate and the supervisor/ the doctoral school/ the faculty. This plan and agreement determines the curriculum, the field of research, the time frame, the budget, further duties of the student/candidate, and alike. This plan is later followed and monitored.

[15] He/she can have an indirect role, in suggesting the reviewers or the opponents.

The Doctoral phase at different locations is more or less strictly *planned* and *supervised*. In any case, a plan is never exactly executed as it was planned. So, after monitoring of the execution, the *plan* has to be *changed* in *many cases*. Changes may be due to problems occurring in the research (a result cannot be found, new and published results recommend another path, another question might have more interesting results, the infrastructure and tools make difficulties, new solutions to be used are available, etc.) but also in the private situation (the personal situation of the candidate has changed).

In any case the *final decision* after the exam is made by a more or less small committee. This committee *decides about thesis and exam*, either passed or determining the overall grade. In the opponent model the exam is the dominant part, the committee decides only indirectly about acceptance of the thesis and an eventual grade. In the reviewer model the committee usually accepts thesis and grade according to the reviews having been written and determines the overall grade by weighting the thesis part and the examination part.

Quality assurance plays an important role in the Doctoral dissertation process, and there are a lot of *built-in steps* on the process or on the (intermediate) product side: there is a supervisor, further advisors/ mentors, supervision is handled regularly in a manner both side have agreed upon. Furthermore, there are phases, reports to be delivered, milestones for partial results, Go or NoGo points, approvals, and so on.

Due to the *selection* in the entrance phase, both the will of the candidate and the engagement of the main responsible person (mostly the supervisor) for getting finally a good result, and due to built in quality assurance measures, the Doctoral Dissertation model was regarded to be a *success* by most of the professors answering to our questionnaire. The *drop-out* rate is only approximately *20 percent*[16]. This is surprising, because most departments and faculties have a close look on quality and quality assurance, and as the doctoral degree is of specific importance in academia. In many of the failing cases it is the economic or personal situation, which does not allow a continuation. So, it is quite rare that the process has to be quit due to inability of the candidate.

4 The Characterization of the Results

We now discuss the *results of the process*, the scientific profile of the doctor and his/her further skills on the one hand, and the thesis and connected publications on the other hand.

4.1 Scientific Profile of Candidates and Doctors

The *purpose* of the doctorate is to make a candidate to a *young scientist*. In this process the candidate is becoming more and more independent. The proof of this new scientist status is given by relevant research and publication of its results. The supervisor and eventually other persons give help in that process.

On the way to the doctorate, the candidate is creating ideas and solutions, which have some originality and produce a *delta* to the scientific state of the art. These results are discussed, described, *presented*,

[16] In a question about quality assurance of the process many answers were given, describing the drop-out rate and giving corresponding arguments.

and defended. Discussion, presentation, and defence are done on an *international* global *level*, at least at the end of the doctoral process.

Of course, *publications* are the dominant part of the open and global presentation and discussion of a thesis' results. Due to the importance of publications they are discussed in a separate section below.

The *international character* of doctoral research is demonstrated by the presentation of results on international workshops and conferences, and the corresponding *publications* in proceedings but also journal articles. Sometimes a candidate *stays* for a longer time abroad in another group – usually one, with which there is some form of cooperation. In any case, some form of a personal and international *network* of the young scientist is built up. This network is helpful for the later career. This career of young scientists after the doctorate gets more and more international.

Summing up: There is one (supervisor) or more persons (mentors, advisors) giving support during the whole Doctoral process. The young scientist at the end of the process has shown that he/she can do independent and creative scientific work and is able to distribute the results. So, the doctorate is a proof of *scientific competences* (creating, solving, discussing, writing, presenting, defending, and networking).

4.2 Thesis, Publications, and Qualifications

Thesis length was specified from 100 to 400, the average being around 200 pages. The *language*, in which the thesis is written, is either the national language or English. The percentage of English written theses ranges from 0 to 100 %, the average is about 70 percent. This reflects a dramatic and still ongoing change in the last 10 to 20 years. Theses written in English will be the absolute standard in the next future.

The *publication form* of a thesis is often a report (internationally available) in the form of a book, often as electronic publication, with or without ISBN. There are specialized publishers for Doctoral Dissertations such that many dissertations appear as official "books". In some eastern countries only an abstract is published, whereas the complete thesis remains as a local copy in the library or as an e-copy on a server.

The format can be a *monograph*, which is the majority. In some countries (Scandinavia and some other countries/ or single universities) the *thesis* is *cumulative*: it consists of an introduction and a summary describing the dissertation as a whole, the delta and importance of certain results, their impact etc. followed by chapters, which are papers already published in proceedings or journals. Of course, there are also mixed forms (a very long introductory part, rewritten chapters following exactly former papers[17]). Even in typical monographs the chapters will borough more or less from former published papers.

There is an ongoing discussion since 10 years about the *professional doctorate* (the motivation is usually that people should be better prepared for industrial life, see discussion below about further soft skills). Professional doctorate means that the doctorate is *not connected to research* but to advanced industrial practice experience [vH 11, 3tu]. We asked whether a professional doctorate is used in the home department or faculty. There was **not one** answer, indicating that a professional doctorate is given by the

[17] This is often the case, if the official language – by law or tradition – has to be a national language

own faculty. Some answers stated that they know that something like this exists, but only in other departments/ faculties/ universities, and mostly in other fields.

Also surprisingly clear it was stated that it is standard today that *publications* are available *before thesis submission*: It is usually not enforced by law (in some countries it is[18]) but it is an absolute "social must". The number is not determined, but in the average *between 5 to 10* workshop or conference proceedings papers or journal papers are written[19] and published or have been accepted before thesis submission. *All* these papers are *in English*[20]. They are mostly *group papers*, i.e. the candidate but also other members of the group and, eventually, the supervisor appear as authors.

Summary thesis and *publications*: Dissertations are mostly published as monographs of about 200 pages, printed (stored) as reports (as e-publication) often with ISBN, a minority in cumulative form. Standard is that they appear in English. Usually 5 to 10 proceedings or journal publications in English have appeared before the thesis was submitted.

4.3 Different Profiles and the Role of the "Doctoral Environment"

In most countries *industry does not reward the scientific competences* of a young doctor. So, there is no extra payment or at least no payment, which is in relation to the extra effort and time the young doctor has spent. This is typically the case in those countries where the doctorate is only used for an academic career.

In the Dissertation process, the *formal position* can be that of a *student*, which is the case in many countries, or that of a fully paid *employee* (a special model only available in Central Europe, i.e. Austria, Germany, northern part of Switzerland, and a few other places), or *something in between* (research with some further duties and with extra payment; stipend from a Graduate School lower than the employee payment). In the questionnaire we asked for the salary or income in relation to that of a fresh Master in Industry.

In the case of the *employee model,* there are *two main differences* to the student model. On the one hand candidates are regarded to be *more independent*[21]. On the other hand they have a full position, because they have *further duties* aside of the research for the thesis. These duties can be education support[22], administration tasks within the group, helping in the management of projects, helping in the transfer to industrial partners, helping in the acquisition of projects, and alike. Here again, independence

[18] In one country even the numerical impact is enforced: a journal paper counts more than a proceedings paper, for both exits different categories from high to low, counting differently. In the case of a multiple authorship, the number is divided, and alike. Before the submission of a thesis a certain numerical publication impact threshold value has to be reached. In another country, 80% of the thesis results must have been published before in proceedings or journals.

[19] Not all are necessarily top quality publications.

[20] In those countries, where the theses are expected to be in the home language (this is e.g. mostly the case in France), there are no cumulative theses. Even if all chapters have been published before, they are translated and a coherent monograph is formulated.

[21] That does not mean that they need not learn to become a scientist in the Doctoral phase. But they start with a Master (formerly Diplom), where they already worked quite independently on the Master thesis. That is why in the employee model the term "PhD student" is not appropriate and "PhD candidate" should be used. Indeed, the starting point is comparable to a PhD candidate in the US after two years in the Doctoral program starting with a Bachelor. The full payment is due to the competition with industry. They also look for good Masters.

[22] For organizing the exercises of lectures, organizing seminars, lab courses, etc.

is growing in the Doctoral phase: whereas at the beginning the candidate is supporting administration, management, transfer, or acquisition, he/she is doing these tasks rather independent after some time. Depending from which sources the candidate is paid, the duties and their composition are different.

Furthermore, the candidate is usually involved in the *supervision* of Master (or Bachelor) *theses*. It is quite typical, especially in more practical and engineering-like Doctoral dissertations that these theses contribute to the Doctoral research project. So, the candidate is interested to get a positive result. As a consequence, a Doctoral project is also a *project of a group of students* and the candidate thereby gets experience in leadership, interface specification between tasks and theses, in cost and effort estimation, and so on. In order to get these students, a candidate – even being paid from a research or industry project – has to be engaged to some form also in education, e.g. seminar or lab work. Altogether, the candidate gets additional *competences* in direction of *group leadership*.

Also, Doctoral projects are often *embedded* even in *bigger projects* of the group (with a company, an EU group project, a project across different fields of Informatics, an interdisciplinary project together with other scientific disciplines, etc). So, in addition to the above competences, also conflict training, regarding the interests of different stakeholders, having a survey on different methods of different fields within Informatics, interdisciplinary thinking etc are trained. Thus, additional *competences* here in the direction of *conflict handling* and *integration* are acquired.

So, in addition to scientific competences described above in 4.1, *further competences* and capabilities are acquired, often called soft skills. These soft skills (but also solving of practical problems) are an important reason why a doctorate in Informatics – and also in Engineering Sciences - is *welcome in industry* [4ING, ac 12].

There is also a further main difference between Central Europe and the other European countries: The d*octorate* in Central Europe is a *degree for* going afterwards to *industry*. About 85% of the young Doctors in Engineering Sciences and Informatics go to industry right after the doctorate.[23]

There was an investigation on *industry career perspectives* of persons holding a doctorate for two academic years in Engineering Sciences or Informatics at RWTH Aachen University [Na 11a,b]. Thereby, 361 young doctors replied. The investigation showed that young doctors have a clear perspective in mind when going to industry. It also showed that they have leading positions after a short time.

Summary of this section: Thesis work in Informatics can be a *combination* of *scientific competences* (creativity, improving the state of the art, presenting, discussing, and publishing on an international level) combined with a lot of further *valuable soft skills* (administration, management, leadership, conflict solving etc. abilities), see [4ING,TU9]. Looking more carefully, these latter competences are not the result of the research work but of the (different) context in which the research is carried out. Maybe that in such a context the studied problems are more application- or engineering-oriented as well. These arguments are **not** arguments for the Professional doctorate[24] [3tu, vH 11], which more aims at applied

[23] In Engineering Sciences – only to a smaller extent in Informatics – the professors are also taken from industry after having shown R&D success in leading positions. So, there is no split into academic career on the one hand and a disjoint industry career on the other, as in most other countries.

[24] Which is mostly a shorter program, e.g. for 2 years. In academic dimensions it is a degree between Master and Doctorate. The aim is professional expertise and not research. Producing Confusion, titles awarded are sometimes similar to Dr. Engg.

development projects than academic research. Research should still be the main part of any kind of personal development connected to a Doctoral degree[25].

5 What is Informatics Research?

5.1 Character of Theses and Corresponding Research

In the questionnaire, we also asked for the *character of Informatics research*, as we were interested also in research in general and not only in Doctoral theses. The answers were not completely satisfactory. One reason was that many different forms of research occur in a given department or faculty. So, quite some answers were given with "nearly everything happens". On the other hand some questions contained terms like "depth" or "breadth", where different semantics could be assigned to[26]. This ambiguity had the consequence that some answers were missing. Nevertheless, we briefly present the results.

We asked for the difference in *style* between *theoretical* or mathematical vs. *applications* or *systems* work. The answer was „approximately 30 : 70", which shows the dramatic change within Informatics. Twenty or thirty years ago, the answer would have been the other way round.

Another question was the *relation* between *core* Informatics on one hand (including the practical fields of Informatics) versus *applications* of Informatics. The answer here was 60:40. So, practical topics of Informatics are regarded to belong to core Informatics.

Another questions asked for *applications* and their *frequency*. The resulting descending frequency order of applications is (1) Engineering, (2) Business Applications, (3) Bio/ Med /Life Science, and (4) Natural Sciences.

Finally, we asked for *Depth vs. Breadth in theses*. The answer – see again the already mentioned limited preciseness – was 40:60. So, many theses do not have a narrow focus, but are more related to different foci, innovative systems building, integration, bridging to application, evaluation, etc. As already told, some answers were empty, others just stated "everything occurs".

5.2 Characterization of Informatics

This topic is discussed short here, as this report is mostly on Doctoral dissertations[27]. However, some of the most interesting *answers for characterizing Informatics research* are sketched.

Informatics is analytic: Informatics is aimed at *understanding and analyzing the essence* of natural and imagined information processing and communication *systems*. It is different in that it explicitly also

[25] In many answers from southern or eastern countries to our investigation about Doctoral degrees in Informatics in Europe there was a similar statement that today young doctors have no chances in academia as all positions are filled. They go abroad or to industry. Also, another statement, often given, said that the Doctorate is not estimated in industry but things are changing a bit. Might be that the closer connection between Doctorate and industry is becoming more standard in Europe.

[26] Depth e.g. was understood as (1) focus, (2) scientific valuable content, or (3) mathematical formalization.

[27] To be prepared also for the discussion about Informatics research at the ECSS at Barcelona, the colleagues, who filled in the questionnaires, were also asked to give a short characterization of Informatics and Informatics research. The authors were not asked for allowance to refer to their characterizations. So, we give them here in brief and anonymous form.

includes the study of artifacts (constructed in the field). A vibrant industry is pushing and pulling the field.

Informatics is constructive: Informatics is mostly *constructing* something, a system, a nontrivial design, a proof. Informatics should be formal, for practical solutions also experience and intuition play a role. Theoretical results should discuss applicability, practical results should be formal where possible. Practical solutions should not be only present their sheer technical details. The way to get the solution, what has been learnt, how method, product, process, and domain knowledge have been improved, are essential parts. So, Informatics is not just building one solution after the other. It is an *intellectual discussion* about ideas, varieties of solutions, learning, and improvement.

Informatics has a specific research cycle: Informatics contains math, engineering, natural science aspects, and nowadays also social or societal. The core is algorithmic thinking and constructive problem solving. A *research cycle* proceeds in the following iterated steps: Specification and conceptualization of the problem, design and analysis of a solution (algorithm), software implementation, experimental and empirical analysis of the software. That is not all but covers a lot.

Informatics has an impact: Informatics research – even theoretical one – may deeply and directly affect the way people live, work, and get entertained. This short cut between *Informatics as a scientific discipline and its large scale effects is what makes Informatics appealing* to the most brilliant students. We should underline the unique potential of innovation in Informatics to preserve its appeal.

Informatics is interdisciplinary: Informatics is 55% Engineering, 25% Math and Natural Sciences, 10% Business Administration, 10% Arts and alike. Also, *Informatics research is getting more and more interdisciplinary*.

6 Academic Conclusions: Characterization, Typical Models, Comparison

We now *draw* some *conclusions from the academic point of view*, namely to characterize and to summarize how different/ similar the Informatics doctorate in Europe really is, regarding the scientific competences. So, we reply to the assumption given in the introduction that there is some comparability and similarity of doctoral research in Informatics, here on the European level.

6.1 Characterization Dimensions

In the following subsection we list some *characterization dimensions* for the doctorate. These dimensions only refer to those characteristics, by which the different models in Europe can be described. We use these dimensions to characterize typical models by giving corresponding attributes for the dimensions in the next subsection.

We now list some of the *dimensions*. The list is not complete. It is mainly what we need for the following *characterization* of typical doctoral models.

Formalized or informal handling of the process: Is the process formalized by the faculty, especially the recruiting and the finalization phase, see above? Or is the group leader able to do it by him- or herself directly? Are there formalized Go/NoGo steps? How many rules and obligations exist?

Curriculum: Is a detailed curriculum necessary for the doctoral program, or only some lectures in the special field? What is the amount of ECTS credit points? Or is the candidate independent enough to look for what he/ she needs? Is the curriculum only for research or are courses for soft skills obligatory?

Status: Is the candidate a student, an employee, or something in between? How much guidance is given in the first part of the process?

Internationality: The percentage of international students is in the average about 20%. There are, however, some universities with a big part of foreign candidates. They usually offer generous grants, are either very well-known, and/or are located at very attractive cities.

Role of the Supervisor: Is the supervisor a mentor accompanying the candidate, or is he/she the "driver" of the process (from selecting the candidate to determining with somebody else the grade of the thesis and having influence on the exam)?

Responsibility: Officially, the doctoral committee and the faculty are responsible for the process. Is the organization of the process in the hands of the faculty or is the supervisor managing it?

Financial Support: Which institution is delivering the financial support for the candidate? Is the money coming from the group leader or is it a bundle of stipends of the department/ faculty, assigned to candidates by a corresponding committee?

Dissertation format: The dissertation is a monograph or it is cumulative, or something in between.

Reviewer/ Opponent: Are the reviewers determining the acceptance of the thesis, or are opponents giving comments, which are discussed in the exam, and the whole committee decides about acceptance?[28]

Examination form: Is the examination a discussion of peers or is it a tough exam? Are the questions around the thesis or do they cover the broad field of Informatics?

Title: Is it an unspecified title like the PhD or just Dr. or Dr. Sc., or is it a specific form as the Dr. rer. nat., the Dr. Ing/ Dr. tech., Tekn.D., or even the Doctor of Comp. Sci.?

Grades: Is the success of the thesis and the exam certified only by passed, eventually with the annex "with distinction", or are grades given?

6.2 Three Typical Doctoral Models

In the panel discussion at the ECSS 2012, Bertrand Meyer [Me 12] introduced in his presentation 3 *different typical models* for the Informatics doctorate. He distinguished between the American model, the Finnish model, and the German model. We extended the names to make clear that there is a region, where quite similar models exist. So, we speak about the Anglo-American model , the Northern European model (Scandinavia and Finland) and the Central European model (Austria, Germany, and northern Switzerland). We are going now to discuss these models in the rest of this subsection using attributes related to the dimensions discussed above.

It should be made clear that even in these regions deviations and *variants* exist. Furthermore, a *lot of mixed versions of these models* also exist in Europe. So these three models do not cover the situation in Europe.

The *Anglo-American Model*: It is a student model, starting with a Bachelor (as told due to the competition many are starting in Europe with a Master). If starting with a Bachelor, there is an

[28] Formally, in any case the committee decides. If the reviews are correct, it is de facto as stated above.

intermediate step, called PhD candidacy, transfer, upgrade, etc. In the US the Master is often something like a bypass degree, if the doctorate is not successful. There is a tight relation of the candidate to the supervisor. The known universities in the US have many foreign PhD students, even if they demand for considerable fees. The first part of the doctoral work contains a detailed lecture curriculum. The title awarded is the PhD. The Doctoral school is responsible for the structure, the procedure, and the quality of the program and its results.

The *Northern European Model* (Some elements of PhD system in the UK and The Netherlands are contained in that model): A candidate mostly has an employee status and can only be accepted if the money for the whole doctoral period is available. There is a supervisor and eventually further mentors. In the middle the title "Licentiate" is awarded in Sweden. The supervisor and mentor(s) have no official influence on the final phase. The thesis is usually a cumulative one, i.e. an introduction and evaluation of the results followed by articles having been published within the doctoral process. The thesis is sent to opponents, the remarks of which are discussed in the final exam. The committee decides about thesis and exam results and gives a "passed", eventually in addition "with distinction". The exam can take for hours. The awarded title is either a PhD or a Dr. Tech/ Tekn. D. Industry appreciates young doctors.

The *Central European model* is embedded in the Humboldt tradition in the sense that all candidates are employees[29], who also do some education support aside of research. That is why the duration is about 5 years. Candidates are regarded to be quite independent from the beginning. The program usually contains only few lectures. The supervisor writes one of the reviews, the second is often a member of another university. The two reviewers decide[30] the grade of the thesis, which is a part of the overall grade (out of 4 or 5 grades). The supervisor has big influence on the procedure and the grade, which demands for a high responsibility. He/she is called doctor father/ mother and is usually also responsible for the financial base of a doctoral project. A Dr. rer. nat. or Dr. Ing/ Dr. tech. is awarded. As described above, a candidate has further duties, which provide a broad competence profile, see 4.3 and [4ING, TU9, ac 12, Hi 11]. That is why industry pays a higher salary and young doctors climb up in the career ladder in industry quite fast. About 80% go to industry after the doctorate.

6.3 Scientific Competences are Comparable in Europe

If we look on essential *parameters* of the Informatics doctorate like the duration of the process, the number of publications, how many students go for a doctorate, the drop-out rate, the percentage of women or foreigners, etc. we can state that the situation is quite *similar in different European countries*. Most of these parameters, are also indicators for the level, quality, and restrictions of a doctorate.

However, there are many *differences in* procedural and formal *details*, rules, traditions and habits. This mainly concerns differences at the beginning and at the end of the Doctoral process.

In my view, it is not mainly the Doctoral research process which makes the *difference*, but the *context* in which the process is carried out, at least if we regard further competences and estimation by industry, see 4.3. In this sense, I see a difference mainly between the Central European employee model versus

[29] Some positions paid by the German Science Foundation (in so-called Graduate Colleges or Graduate Schools, about 10% of all) follow a model which is in between the employee and the student model. Furthermore, there is the tradition of so-called "external" dissertations, where persons do the research in parallel to their work in industry (in Informatics something like 5%).
[30] Officially it is the individual doctoral committee of about 5 persons. They usually follow the suggestions of the reviewers.

the Anglo-American student model. It is not a question of the quality of research and thesis but of different profiles of Doctoral theses and graduates, which induce different estimation in industry.

Informatics has changed dramatically in the last thirty years, from a part of Applied Mathematics or of Electrical Engineering to an *own and independent scientific field*. But there is still a *broad internal spectrum* for research, from mathematical/ formal research to applied and engineering-like research. In most faculties both exist peacefully aside of each other. One can clearly state that the number of applied or practical research theses or theses with engineering like methods used has grown dramatically.

7 Political Conclusions: Industrial Importance and Necessity of Unification

In this section we discuss the *value* of the d*octorate* for the *industry*, which is different throughout Europe. Then, we give an answer to the question whether some political actions should be started to unify the different approaches of Informatics doctorates in Europe.

7.1 Informatics Doctorate in Europe: Interesting for Industry?

We have seen that the *quality* measures are *comparable* and the *culture* for getting a doctorate in Informatics indeed is quite *similar* over Europe, the latter if we concentrate on the essential aspects. Whereas quality and culture are similar, the *context is not*.

We find the *students model* mostly accompanied by a curriculum, only devoted to research topics and to research competences. This is traditionally in those countries, where the doctorate is only a degree useful for an academic career. On the other side we find the *employee model*, where candidates are regarded to be more independent, they have a full salary, they are doing project work - often on applied topics - and thereby also get other and further competences, such that the degree is appreciated by industry [4ING, ac 12, Na 11a,b].

Correspondingly, there is a *difference* in the *economic value* of a *doctoral degree*, namely in the estimation of Doctoral research and its title by industry. This fact is mostly not related to research and scientific competences but to the context, in which the doctorate is carried out and further competences are achieved, see again subsection 4.3. Mainly, the estimation is only found in Central Europe. Again, this estimation is not a matter of legislation.

The *situation* in *Engineering Sciences* is quite similar to that of Informatics ([4ING, TU9, ac 12, Hi 11, Na 11a]): The measures for research quality are again quite similar. Also, there is a variety in procedural aspects, a variety of contexts of the process and, therefore, further skills, different profiles, and economical importance of the doctoral degree, as discussed above. So, it seems that there is a special way for getting a doctorate in Engineering Sciences in Central Europe. It might be that there practical questions are also higher appreciated. This, altogether, implies a greater attractiveness for industry.

7.2 Is there a Necessity for a European Unification of Regulations?

In our investigation we have only indirectly looked at *Doctoral research quality* by regarding *outside and output parameters* as duration of the process, age of the doctor, gained publications, etc. In this restricted sense we have seen that the quality of the dissertation and the Doctoral *education* is

comparable throughout Europe. We have also seen that there are a lot of procedural and regulation *differences* and varieties, due to different habits, traditions, and legal aspects.

The question is now, how important these variations are. To answer this question, we should primarily look on the *essential aspects* of the Doctoral education. In my view, there are three: (1) A *candidate*, who is intelligent and ambitious and who is spending an essential period of his/her life in order to make deep research, become a scientist, and collect corresponding competences. (2) A *supervisor* devoted to good practice of research and education, who is precise and fair to the candidate, and who cares about the progress of the candidate's research and development. (3) A *faculty* giving a framework for the Doctoral process to control this process, thereby following good academic practice.

These *essential aspects* can be *found* in *any specific process* of the above variety, following any kind of habits, traditions or legal constraints. So, the main topics are the three aspects of the last paragraph and not the variety in procedures. Taking these essential aspects, we conclude that the *PhD culture* throughout Europe is *similar or at least comparable*.

We did not look into theses, but regarded the outside attributes (duration of process, age of doctor, length of thesis, number of publications, etc.), which allowed to make an easy comparison. Thereby, the assumption of the introduction can be approved: The *scientific quality* of *Informatics* doctorates *in Europe* is quite *similar* or at least *comparable*.

Furthermore, it is never possible to have one and the same quality; a good *threshold quality* should be available such that the title is disserved by the demonstrated achievements. In those faculties giving different grades for the doctorate the differences can be expressed by *different grades*.

So, in my personal view there is *no need* to think about a *new, standardized, and uniform European Doctorate model*, as the essentials are not touched by any existing legal model, also not by any new standard model invented. The scientific essentials of the Informatics doctorates are comparable and satisfactory and the outside quality is at a similar level. So, the doctorate in Europe should keep on to be different implying a colourful variety, as it is with languages and cultures in Europe.

Any kind of *change*, being domain-independent and thus remaining on the *syntactical level* (as [By 13]), can only introduce legality rules and constraints. These are not really on the level of quality. The three aspects of above indicate, what quality is about.

There are *interesting aspects* and procedural parts in many models which we have investigated. If a university or country finds them attractive, they can be *taken over* and built into the local doctoral procedures if they are compatible with the local habits, traditions, rules, and constraints. This way seems better to me than imposing something new in a top-down manner.

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