Forming the next generation of European interdisciplinary scientists

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Abstract. The centrality of well-trained innovating doctorates to the future of the world's cultural and economical well-being cannot be underestimated. To meet with the challenge, Europe has much invested in providing unifying guidelines of common graduate studies' goals and practices. Nonetheless, a significant heterogeneity in their implementation, largely due to the difficulties in adapting and changing of existing frameworks, are evident. In addition, the interdisciplinary character of future research dictates cooperation of players hitherto isolated within current research and educational structures. As actors, we take a concrete approach of identifying the essential components of an ideal interdisciplinary graduate school, built upon ingredients of successful international examples, to set a pilot interdisciplinary graduate program. The basis of our recommended Graduate Center is the creation of common language between students and researchers from different backgrounds. It encompasses the following key ingredients: a quality-assuring international governing scientific council; a physical centre including seminar rooms and well-equipped working space for students and visiting professors; individualised flexible curriculum, motivating students, reinforced in their primary discipline, to interchange their knowledge; an international network of high-level researchers splitting workshops between their established curriculum and students' choice of seminars and an active thesis tutoring committee encompassing hosting-lab-independent specialists in related disciplines. In order to reach the critical mass of expertise needed to meet these ends, a concerted action is necessary between establishments within a coherent geographical setting (city (e.g.,), region (e.g.,) or country (e.g., Finland). In order to assure proper financial support, we suggest that Graduate Centres will be autonomous bodies capable of attracting funding not only through their 'mother' establishments but also independently from EC, research foundations and the private sector.

Keywords. Graduate Centre, graduate school, interdisciplinary, PhD program, life sciences

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1. Background

1.1 On the importance of innovating current doctoral programs

The strength of Europe relies on the production of high quality products by a well trained workforce, as a result of a rich past of nurturing scientific and engineering knowledge. While the thrive across the world for scientific excellence is highly welcomed, the leadership position Europe had in the past centuries has faded out in front of the supremacy of the American scientific achievements and is further endangered by the rising emphasis and investment in scientific education in India, China and the 'tiger' countries. Only few British and Swiss universities are stably located in the world's top-notch university rankings, where Asian establishments quickly advance ahead of most European counterparts. In order to play a motor role in the 21st century and face future challenges, Europe needs to adapt to the globalization of the 'brain business' by continuous innovation. The challenge is further emphasized by the retirement of 30 to 50% of the European scientific work force within 10 – 15 years while student's enrolment into postgraduate studies is in a continuous decline. Indeed, European decision makers share this diagnostic and measures as raising the GDP percentage funnelled to research and development and unifying graduate studies were declared (*see* Bologna, Lisbon, Glasgow declarations). In practice, attracting the next generation of talents by offering high quality training is the key priority given that the initial trajectory of a scientist is the best indicator of her successes in the future.

Constantly evolving education at all ages and levels in our ever-changing world is crucial. In this article we specifically address the postgraduate scientific level as we feel that it is at this level that maximal impact on a fast timescale can be achieved. Furthermore, while in the past decades emphasis was given at specialized training in classical domains (*i.e.*, individual branches of biology, math and physics where theoretical and applied aspects were separated), 21st century doctorates need to be not only experts in their major domain but also fluent in parallel disciplines, enabling innovative research at emerging interfaces where future innovation is to be expected. A generation of motivated interdisciplinary doctorates who are critical thinkers capable of connecting theory and practice with proven experience in conceiving and managing innovative projects will serve as the backbone for the society of knowledge by integrating and reviving basic and developmental research as well as education at all levels.

1.2 Doctoral programs – a European perspective

In the U.S.A graduate schools providing rotations between laboratories and across-borders course and seminar curricula and follow-up and evaluating tutor committees to all students are common place from the beginning of last century [1]. Such programs are still rare in Europe and where they exist, training in the form of courses and workshops are scarce and under-funded. Training in transferable skills is largely lacking and international collaboration in research or training is rare. Students, under-paid and in most cases without social rights, are mostly constrained to sole interactions with their supervisor thus susceptible to personal conflicts. Concomitantly, the average thesis duration is 6-7 years and 3- 4 years in the USA and Europe, respectively. Indeed, while PhD graduates are highly considered in the American job arena, in Europe they are considered too specialised, have lower chance of getting a job compared to engineers and would gain less of a salary (*e.g.* 25% less in France).

Since the start of the Bologna process, several studies addressed the current situation of doctorate studies and put forth suggestions for improvement and implementation of the ambitious Lisbon objectives. The main findings reveal a high heterogeneity of doctorate programs at all levels, starting from governmental policies and down to significant differences even within the same university. The diversity is reflected in their autonomy (*vis a vis* the corresponding faculty, university, or staten), curriculum offered (from none to hefty load of frontal courses), doctorate status (from 'cheap labour' to young researcher), the extent of tutoring (none, optional, obligatory) and the time-course of studies (3-6 years).

This analysis brought the setting of common recommendations for European doctorate programs, as reflected from the European University Association reports [4] commissioned by the EC. In their main conclusions they (i) define research as the core part of the doctoral studies (adding a call for openness to wards the outer-academia employment world)); (ii) define PhD students as early stage researchers (*i.e.*, professionals with commensurate rights); (iii) define the program duration as 3 years (4 years where interdisciplinarity is evoked); in order to promote interdisciplinary studies, (iv) student mobility should be supported, geographically but also between sectors; (v) diversity of European doctoral programs should be highlighted and (vi) innovative structures should prevail to assure critical student mass within universities that assume their responsibility towards the doctoral programs. This significant attempt to provide broad guidelines while reaching a compromise between the different European players falls short in describing their translation into practice. Indeed, with few exceptions, most European countries are far behind in implementing these guidelines. While across Europe graduate/doctoral schools were formed, their role is mostly limited to administrative purposes.

This is largely due to the lack of appropriate financing. In France, as example, money invested per student in universities falls by half as compared to high school. Given the importance of the topic, key players at all levels should be involved, with the EU taking a major role in financing directly graduate programs, followed by national agencies, ministries, regional and city authorities. This should be seen as investment, the fruits of which are estimated to contribute significantly to the GDP. In the USA, public as well as private funding agencies that were initially targeting research (as NIH, NSF, Howard Hughes) have declared that while scientific research is their key objective, graduate program is within their responsibilities as it constitutes the rate limiting step. It is notable that while in several countries private foundations play a decisive role in the advancement of scientific education this is still the exception rather than the rule.

1.3 Doctoral program as a national network of graduate schools – a Finnish perspective

Finland serves as an outstanding example of an innovative concerted effort that goes even beyond the above recommendations and could serve as an important case study [2]. The Finnish economy, formerly based on subsidized agriculture and natural resources (as the paper and pulp industries), was transformed in the past 14 years to become the world's most competitive country (OECD and WEF rankings). This metamorphosis was gained by not only doubling the GDP fraction invested in R&D (to 3.5% in 2004) but by implementing a radical and visionary science policy. At the heart of the policy is the recognition of the formation of new generation of scientists as the key component to an innovative and competitive society. To this end, a national graduate school system was created, involving all universities and research institutes. The aims were to improve supervision of Ph D students,, secure the quality of the theses (with duration of 4 years), internationalize training and activate collaboration between researchers and with industry. The formed graduate schools are renewed every 4 years, based on the quality of the proposed training in research areas and transferable skills, as well as by best practices to support the work of the PhD student. In order to assure critical mass, most schools are organised in nodes. The PhD graduates are selected (1 of 5) are selected by their track record and research proposal qualities. As a thumb rule students are expected to spend 75% of their time in active research. The rest of the time is devoted to courses, seminars and workshops (*mostly in English*) developing not only specific scientific domains but also transferable, pedagogic, management skills and ethics. Moreover, recognising the lack of world-class expertise in different research domains, world-class experts are invited to participate in their graduate programs as foreign visiting professors and students are highly encouraged to spend significant portion of their studies abroad, financed by the state through the Academy. In addition,, Finnish students have created local and national organisations , to promote interactions between them and organise conferences where foreign guests of their choice are invited. Lastly, the quality of the thesis work is assured by constant follow-up of the student's work by experts outside of their lab throughout the 4 year period.

UK serves as another example of a concerted effort towards a coherent and effective graduate schools, for details see the UKGrad (www.grad.ac.uk) and UCL (www.grad.ucl.ac.uk) programs.

2 The Challenges ahead: Interdisciplinary scientific education

The term ‘interdisciplinary research’ was coined to describe the rising importance of collaborative effort across scientific domains, a hallmark of the forefront of contemporary research. The term suggests a synthetic, integrative approach where scientists from different backgrounds formulate and address jointly a common problem. The importance of interdisciplinary research is widely acknowledged [3,4] and is reflected in the increasing number of publications in the leading scientific journals co-signed by labs from different domains. The importance of *Interdisciplinarity* goes beyond research practice; it is an intellectual framework and as such can serve as a key component in scientific education. Interdisciplinary doctoral training at its best can form students capable of adapting to the pivotal aspect of modern life: a continuous change. Such doctorates will perform better in academic research and will be increasingly valued in the private sector, where flexibility, cooperative problem-solving and communication with different mindsets are essential. In the past 5 - 10 years, all leading American and many world-leading graduate schools included an interdisciplinary program to their agenda with varied level of success, as can be predicted given the background of disciplinary traditional doctorate programs, inhospitable to interdisciplinary work [5].

Weaknesses	Strengths
"program on paper" run by different departments with conflicting interests	Creation of an autonomous physical space and governing structure
budget relies on a unique source (governmental) or shared between conflicting programs	Independent budget of multiple sources
Students are passive in front of a fixed curriculum	Student-tailored seminars
Disciplinary based teaching by mainly non-active scientists	Innovative teaching by best active researchers of proven interdisciplinary career
No special selectivity; for students who "don't know what to choose"	Small number of the very best students selected
Students follow projects dictated by their hosting labs	Students have responsibility and autonomy on project choice
Projects are only technically supported by other disciplines	Good projects are defined by being at the frontier of different disciplines
Students are confined to a single-discipline lab	Students are often working with labs of different disciplines
Lack of interaction in the international arena	Active flux of International scientists, visiting professors and students
Lack of interaction with the non-scientific environment	Active involvement of students in scientific communication and education
No external evaluation during the thesis; only at the thesis defence	Students are evaluated and receive support from external tutors from different relevant disciplines throughout their thesis

Table 1. Key components for a successful interdisciplinary doctoral program identified by a non-exhaustive analysis of existing programs.

Indeed, interdisciplinary program is by definition a boundary-breaking activity. Several conclusions may be drawn by addressing the strengths and weaknesses of existing programs as depicted in Table I. This analysis can serve for amending existing programs as well as for creating future programs.

3. Creation of a new Interdisciplinary Graduate School

We focus on the creation of *de novo* interdisciplinary schools rather than amending existing programs [5]. This is a daunting yet an indispensable task aimed at forming the researchers of tomorrow. We provide potential ingredients of a recipe that takes into account lessons drawn from existing programs as well as from our experience of launching and mentoring an interdisciplinary master program (www.master-aiv.org**),** an interdisciplinary college (Paris Interdisciplinary College) where scientists of all ages can share their experiences and engage in interdisciplinary workshops, and setting up an interdisciplinary graduate program that will start in 2007. Interdisciplinary research relies as much on diversity of disciplines as of people. It is therefore important to assure openness towards students of different backgrounds, social and cultural. To this end all graduate school activities are conducted in a language that all can understand (*e.g.* mostly English).

3.1 Autonomy

The graduate school should enjoy maximal governing, scientific and financial autonomy. Critical mass of interdisciplinary students and mentors is assured by assembling key institutions (universities, engineering schools (*e.g.*, French 'grandes écoles'), research centres) within a coherent geographical area. Transparent and independent governing board, directed by the active mentors of the graduate school**,** will propose innovative courses and will build an attractive program. The financial autonomy is essential for fund raising from potential added sources as the appropriate ministries, region, EC, international funds, private foundations in particular and the private sector at large. To this end, a research foundation status could be obtained. Finally a scientific autonomy, guaranteed by an international scientific board, provides for evaluation, curriculum approval as well as recommendation for fellowships and prizes thus avoiding any conflict of interests. Overall, such autonomy will result in high visibility both nationally and internationally, capable of attracting the best mentors and students.

3.2 A physical centre

The importance of a unifying territory to the success of interdisciplinary studies was succinctly stated by Golde and Gallagher [5]: "Students need to find faculty to provide intellectual input and fellow students to provide collegiality, emotional support, and a safe arena for formulating and honing new ideas. Working in a nontraditional or emerging field, however, makes it more difficult to develop this type of community. Often the people who would be natural colleagues and collaborators are in several different departments… This is a particularly challenging obstacle for students to surmount, as there are few mechanisms connecting them to faculty or students in other departments. An interdisciplinary student is vulnerable to feeling intellectually homeless, without a place to share interests and long-term goals.” To overcome these hurdles, fully facilitated seminar room, convivial coffee room, meeting room and an open-space working room should be consecrated to the program along with offices for administration and visiting professors (see below). Such infrastructure will ensure day-long conviviality through its attractiveness to both researchers and students.

3.3 Choice of students, projects and hosting laboratories

The interdisciplinary program relies on high level students skilled in sharing their knowledge with their peers and directing a thesis project based in large part on their initiative and intuition. Thus, both strong disciplinary background is mandatory (M.Sc. level or equivalent) and open-minded and highly motivated personality capable of withstanding the unknown path of research [7]. These traits will be identified by interviews with a selection committee from within the international scientific council. Students will be given 6 months from the start of the program to prepare a detailed research proposal that would be evaluated and approved by their hosting-lab independent tutoring committee *(see below*) as a necessary step for fully enrolling in the program. The quality of the project is judged by being at the cutting edge of different disciplines. The choice of the hosting lab is left to the discretion of the student yet the graduate school ensures that the lab is the best match to pursue the proposed project. When judged beneficiary, the graduate school will match a second lab with a complementing expertise.

3.4 Thesis work

The thesis supervisor is scientifically responsible to the success of the thesis. In addition, every student will be followed by two tutors (chosen by the Graduate School) of matching competence to the study domains. They will follow the Ph.D. student throughout his study. In particular, they will represent the graduate school in the three key requirements of the thesis work detailed below. These 'checkpoints', rather than 'exams', serve as an independent quality control mechanism that should ensure their status as *research* students within their labs and as an essential guiding process that will ensure their project's and their own well-being. New web-based tools can be used to facilitate the follow-up and interaction between the student, the supervisor and the tutors (*see* www.grad.ac.uk)

The average duration of the thesis is about 4 years. While European consensus was initially set to 3 years, most thesis are finished in average in 4 years and there’s a wide agreement that interdisciplinary thesis work is more demanding and should be given an additional year. Appropriately, lobbying within the financial supporters, mainly the state and the EC should be pursued in order to obtain financing for the fourth year. Other financial venues include specific fellowships endowed by foundations and, importantly, temporary teaching positions having an added value of the experience gained.
The *thesis timetable* consists of the following steps, each accompanied by oral presentations at the graduate school: (i) *Research proposal* - Up to 6 months from

starting the thesis work as described above. (ii) a concise *Interim report (month 24)*- containing a summary of the results achieved to date and plans for future work to be discussed with the tutors.(iii) *Final report (month 42)*- summarising the main results of the research and serving as a basis for writing the thesis. The review of the report by the tutors is not only required for the submission of the thesis (*see below*), but also in order to provide the student with helpful comments on the style and organization of the thesis. *Thesis presentation (month 45)* - The doctoral thesis represents the student as an accomplished scholar [6] through his ability in scientific writing and comprises an integral part of the research work itself which can reflect on the whole. The thesis must convey to the reader, clearly and unambiguously, the main line of thought which led the investigator to his conclusions. It should be aimed at the professional in the subject but at the same time, bear in mind readers whose interest is not specifically in the subject of the research. A committee consisting of the students' supervisor, tutors and two external examiners will meet with the student (*publicly*) and following his presentation, will convey their appraisal and criticism and decision of granting the Ph.D. degree. The last three months are devoted to finalisation of manuscripts and actively planning the next career step with guidance provided by the graduate school and the student’s tutors.

3.5 Tailored teaching: visiting faculty network, curriculum

As described above, the general emphasis is on formation of scientists through lab work with meagre importance of teaching. Indeed, the overall sentiments are that frontal formal courses are obsolete. However, one cannot underestimate the role of ‘good’ courses to the development of critical thinking and analysis skills and to their scientific culture. An interdisciplinary doctoral program assembles bright students with strong disciplinary background from prior degrees. Such an intellectual blend can serve as fertile nurturing grounds for common quests of knowledge tackled from different angles if mentored properly. Minimal intervention is called for; students share the responsibility of their own education by sharing their knowledge in a continuing ladder of questioning that would lead to unanswered scientific questions that are likely to be pertinent as they passed the scrutiny of different disciplines. Obviously, high level mentoring of such processes would be valuable for the graduate students. The graduate school mentors are to guide the process by providing the appropriate background and filling the ‘gaps’ where needed through a dialogue with the students rather than through frontal courses. As a rule of the thumb, 50% of such semester seminar curriculum is defined by the graduate school mentor in charge whereas the rest is decided built upon the arising interests of the student participants who are responsible in moderating the meetings, coupling students from different backgrounds for each presentation. Not every leading scientist is capable (or has interest) of high level mentoring and teaching based on the above guidelines. To assure the quality, diversity and attractiveness of the program, teachers, world-class leaders in their fields, will be invited.

Courses include scientific courses such as initiation and advanced courses to modelling, statistical analysis, experimental design, but also history, philosophy and ethical aspects of science as well as seminars addressing topics at the interface between disciplines. Furthermore, graduate students should be trained to learn skills that will be essential for them in most of their future activities (inside our outside of the academic world) such as being able to find creative solutions, criticize firmly but sensibly, manage a project and a team and their various dimensions, be able to write reports and grants in English, communicate and collaborate with very different people and learn continuously to remain at the front of knowledge.

4. Perspectives

The above skills are essential for future leaders in many if not most human activities and so we can expect that a PhD that will have actively learned such skills are likely to have a bright future in many career paths. We will focus here on the future of those that will chose to remain in academic research. Given the high level training such students will have achieved following such programs, they will certainly aim for post-doctoral positions in places where they will be able to maintain a high level of scientific exchanges while developing further their own projects and abilities in places that will given them the required support . The Bauer centre in Harvard or the new MedILS (www.medils.hr) are offering such perspectives to young and talented scientists that would want to develop their own projects in a nurturing environment where they will be able to learn throughout the most recent advances and use them to contribute to original discoveries. One can only hope that the number of such places will grow building on places where innovative learning and teaching takes place.

In general, promotion of centres that provide autonomy and high-level interaction to young scientists both before and after their PhD will increase their potential and therefore their career prospect as well as their added value for society. Therefore creating a network of graduate and post-graduate centres allowing the development of original projects should be a priority for the European knowledge society. Given that the world is trying to attract the best young scientists and that “intellectual capital goes where it is wanted and it stays where it is and will be well treated” (Lesley Wilson, Secretary General EUA), creating such nurturing hubs for creative young scientists will be a must for any world-class academic environment.

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Appendix I – Lessons for a graduate school program following Jim Watson advice: "Succeeding In Science: Some Rules Of Thumb" [1]

In these rules of thumb, Jim Watson, in his blunt, not politically correct way, offered advice to those that wish to succeed in science. His very words are used among quotation marks. Here, we freely adapt his advice to individuals to a graduate program that aims at maximising the scientific successes of the next generation.

Rule #1: "avoid dumb people"

It is important to be able to detect and keep off limits people that would not be able to contribute positively to the development of students. Graduate schools should aim at avoiding such students and mentors. However, as any selection procedure has its errors and as stupid ideas can be uttered even by the brightest, developing critical thinking and the ability to defend one's idea should be a priority of a graduate program as it is probably one of the most efficient strategy. In this rule, Watson also emphasised the importance of interacting with ever more challenging people as a way to progress intellectually, making the parallel between the scientific game and any other challenging games. Ensuring a critical mass and a flux of interesting people of all age and academic levels should thus be a priority for a graduate school.

Rule # 2 "take risks"

One way to encourage students to take risk is to tell them that "the greatest risk for a curious intellect is to spoil your life by making it a boring one" (see Rule #4). A graduate program can encourage risk taking by promoting an atmosphere where successes are rewarded and where individual failures are not punished but are discussed individually and collectively to serve as lessons to maximise learning. Furthermore, mentors should be examples of successful high-risk high pay-off careers and should be able to explain how to handle risky situations. Jim Watson himself advised rule number 3 in such cases;

Rule # 3 "have a fall back" so that you can survive if you fail; as failing is part of risk-taking and as we learn a lot from failures, one should not be afraid to fail (fear would block creativity and risk-taking), measures have to be taken to ensure survival of the risk-taker.

The graduate school should ensure a safety net for the risk-takers. This could be done partly by adequate mentoring by the evaluating tutor/supervising committee and by offering to students both time and opportunities to recover from a fall by identifying alternatives paths both within and outside of the academics. For instance, one should be able to offer an extra year to finish the risky project or to offer to those interested retraining to become teacher, patent officer, journalist, business executive...

Rule # 4 "never do anything boring" (*"I'm not good enough to do well something I dislike. In fact, I find it hard enough to do well something that I like").*

Clearly motivation is an essential component of both learning and research and being forced to do things without seeing their relevance leads to boredom. Boredom has even been programmed in robots to keep them exploring new facets of their environments rather than being stuck in analysing ever finer details. In this light avoiding boring things is looking for new sources of relevant information and ensuring that the time spent learning leads to increased important knowledge. Lessons for a graduate school would be to offer a wide choice of stimulating and interactive up to date courses where motivated students would be actively participating.

Rule # 5 "if you cannot stand your real peers get out of science"

Success in modern science relies on interaction and cooperation with others as they are not only essential sources of relevant information but because additional ideas sprout from collaborations.. Information is a special kind of public good that is not lost when transferred thus generating positive sum games among co-operators. Thus, a graduate school should teach students by practice the value of cooperation, information transfer among students and informal interactions. Emotional intelligence were shown to be a key component of scientific success [6], social skills and interactions should thus be fostered by creating a nurturing atmosphere where conviviality and cooperation can reinforce each other.

[1] **J. D. Watson** (1993) **Succeeding In Science: Some Rules Of Thumb** The complete original Watson text can be found at http://www.chialvo.net/advice.htm; adapted from a talk given on March 2, 1993, at Cold Spring Harbor Laboratory during a symposium honoring the 40th anniversary of the Watson/Crick discovery of the DNA double helix and printed in Science v261, September 24, 1993.