TUNING EDUCATONAL STRUCTURES IN EUROPE

BROCHURE of the Physics Subject Area Group

CONTENT

July 2007

As a part of the Tuning Validation strategy, our Physics Tuning Brochure was submitted to a Panel of nine Physics experts at the end of February 2007, care of the Tuning General Co-ordinators, who asked the Panel to answer seven specific questions about the Brochure. The Panel and the Tuning Physics Area Group met in Brussels on March 23, where a preliminary oral assessment report was presented to the Physics Group by the Panel. On the basis of the subsequent discussion within the Group and on the basis of the Written Report by the Panel (received in June 2007, see general part below), the present revised Physics Brochure was edited. The part of the Panel Report, which deals with specific suggestions for improvement has been left out, but is reflected in the several improvements, which appear in this final version of the Physics Tuning Brochure

Validation Conference of the Natural Sciences in the Tuning Project
Comments of the Physics Panel

General

In general, the panel was very impressed by both the approach of the Tuning Project and the specific document describing the physics section. We felt that the Project was a very helpful adjunct to the Bologna process; together, we saw these two developments as attempting to achieve the twin goals of maintaining consistency and transparency in higher education across Europe, while allowing, and even encouraging, diversity of provision. These factors are particularly important in the context of physics. Physics is becoming increasingly important in areas outside its traditional boundaries and governments across Europe have identified an urgent need to increase the number of graduates in physics and its related disciplines. In addition, physics has always been a subject with extensive international links and the harmonization of the various systems of higher education is essential to enhance the mobility of physicists from country to country.

The physics document is impressive. It is both well written and well structured, with many examples of good practice. The Panel identified the paper as a working document that would change organically with time. Its worth is twofold. First, it offers a transparent template for universities both to develop new programmes and to revalidate existing ones. Second, and equally important, it provides a description of what employers can expect from a physics graduate, regardless of his or her country of origin. It follows that an essential aspect of the project is dissemination. Considerable thought needs to be applied in order to determine how best to encourage professors across Europe to use the document when they are considering their degree programmes; it will not happen without explicit encouragement. Equally, employers will not naturally seek out the document.

The other aspect of dissemination, of course, is to spread good practice between different universities in different countries. One of the most useful sections of the physics document was the set of comments from active teachers, for example on how they achieved the various competencies or how they developed and integrated novel learning and assessment strategies. Such a store of interesting ideas should not be lost and the Tuning Committee should consider seriously the most effective method of sharing these good ideas.

In considering the document, two general points emerged that may also apply to other subject areas. The first is that neither in the general documentation nor in the specific physics paper was there any consideration of the variability of the knowledge and competences of students on entering higher education. In a physics context, for example, in some countries, entrants might have more extensive experimental skills or a deeper mathematical knowledge, possibly as a result of early specialization. Such differences in culture mean that one should be extremely careful in simply describing a given cycle as a specific length of time. In these circumstances, the emphasis on outcomes rather than simply the hours of student activity is entirely correct.

A separate but related point is that the descriptions of the degree profiles, particularly for the first two cycles, should be seen as *minimum requirements* rather than as limiting descriptions. That is, no university should be disadvantaged if it offers, say, a first cycle programme that exceeds the first cycle requirements. In some countries, it may be that the requirements for the second cycle are satisfied but that the split between first and second cycles is not quite as specified. This should be perfectly acceptable. The issue is discussed in more detail below.

Specific Questions

…
The Panel agreed that it was correct to focus on the “pure” physics degrees rather than including the various other subjects, usually with a more applied character, that are related to physics. The description gives an accurate picture of how physics is taught in the various higher education institutions.
…
It is worth repeating the general comments above on the purpose of the document, which is to help universities design programmes and to provide information for employers to understand what skills and knowledge they can expect of physics graduates. The document is largely successful in achieving these dual aims, although there were a few issues that the Panel felt should be addressed.
…..
A common problem across Europe, and much of world, is the shortage of well qualified physics teachers. Ideally, these teachers should have some sort of a degree in physics or an equivalent qualification. Although the mechanisms for the training of teachers do vary considerably across Europe, the Panel felt that the document should consider this issue in more detail. In particular, there should be some indication of the minimum levels of skills and knowledge to be able to teach at secondary level.

The list of occupations is helpful and emphasizes the difference between the first cycle degree, which is a seen as a general preparation for work, and the second cycle, which leads either to research or employment in a scientific or technological area.
…
In general, the competencies are well chosen. One of the primary and most attractive features of physics programmes is the transferability

of the skills acquired by students.
…..
The Panel supports the emphasis placed on learning outcomes rather than hours of activity as the basis for the level and subject descriptors. This approach can best enable the community achieve its goal of encouraging consistency while embracing diversity. However, we recognise that there is a tension between this approach and the more easily applied notion of credits as a function of student workload. While it is clear that, on average, one would expect students in different countries to achieve similar learning outcomes with similar workloads, the different educational structures and cultures and, particularly, the different input standards to the first cycle, mean that any attempt to harmonise the length of studies in terms of hours of study is going to be very difficult to achieve. On the whole, we believe that the emphasis on learning outcomes is the better approach.
…
The Panel found the Tuning approach to teaching, learning and assessment to be very constructive and was particularly impressed by the many and interesting examples cited for the various aspects of teaching, learning and assessment.
….
Given the relatively brief period the Panel had to discuss the document, we did not spend a great deal of time discussing quality issues, principally because were broadly satisfied with the Tuning approach. We approved, in general, of the key elements for designing a study programme. We agree also that Tuning can play an important part in helping the world to understand the nature of qualifications in higher education and we recognize the vital need for the quality enhancement process to be ongoing.

Finally, there are two issues that we would like to mention. The first is that, as discussed above, one cannot approach any comparison of quality between different countries without recognizing the large cultural differences between the countries, in terms of teaching traditions and the variable knowledge and skills of students on entry. One very useful task for the Tuning project would be to educate academics, not currently engaged with either Tuning or Bologna, in the different approaches used by higher education systems across Europe. Ignorance is not bliss in this context. Second, many, if not all countries, have a well established quality framework. The Tuning document should be clear on how the Project will interface with these bodies.

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Hungarian Academy of Sciences
Vice Pres. HAS, Prof. R. Eötvös & Technical Uni, Member of EURAB & ERC

Prof. Stefan Antohe
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TUNING PHYSICS AREA GROUP BROCHURE

Aims of the Brochure and Executive summary

The main aims of this brochure are: i)providing the academic communities a transparent guide for planning or re-planning physics degree courses; ii) presenting the main aspects of a physics curriculum and its related opportunities to potential or already enrolled students iii) helping employers and different stakeholders to understand the competences of the physicists who work in their enterprises. In the words of the Validation Panel, this brochure attempts "to achieve the twin goals of maintaining consistency and transparency in higher education across Europe, while allowing, and even encouraging, diversity of provision".

Physics is a natural science, strongly based on experimental findings and on physical theories (Section 2). These latter usually require deep mathematical knowledge and skills. Physics is cumulative in character, requiring an ordered progression in the studies. Research and education in physics have a world-wide scope since long, thus demanding and at the same time providing mobility opportunities for the physics students.

A physics graduate is apt to a great variety of jobs, from research careers to financial positions (Section 3.1). "The list of occupations emphasizes the difference between the first cycle degree, which is a seen as a general preparation for work, and the second cycle, which leads either to research or employment in a scientific or technological area"[1].

A physics graduate owns a rich package of transferable skills (Section 3.2 and 4). In each cycle the competencies have different relevance, as described in detail therein. Each competence is referred to its appropriate Dublin Descriptor(s)[2]. The Tuning list of Physics specific competencies is given in Section 4 for the first and second cycle together and, separately, for the third cycle.

Section 5 is a short review of the Tuning network background papers, which helped us in developing the common reference points for Physics.

Section 6 identifies a rich set of organisational and qualitative variables, which affect the learning/teaching environment and student/teacher habits in the different European systems. Many examples about approaches to teaching, learning and assessment are then given from the direct experience of the contact persons at the Physics Tuning network universities, Our general idea was to assemble a kind of inspiring handbook on specific competences, to be used by the Tuning community and possibly by a wider European audience as common reference points in curricular planning or revising. We focused on those approaches, which we thought to be useful for developing the most important skills in the first and in the second cycle (see respectively Section 6.3.1 to 6.3.2). A special attention, even if it is limited, is given to assessment procedures, since "assessment drives learning" *and the way students commit themselves in their private study time.*

Finally we gratefully acknowledge the Validation Panel, whose careful and detailed remarks made it possible to improve the present brochure considerably (in the body of the following text we do not quote the Panel as many times as it would deserve!). We warmly thank all its Members!

From 17 Cities in Europe, 11 July 2007 *The Physics Tuning SAG*

[1] Again from the Written report of the Validation Panel

[2] The importance of the Dublin Descriptors in curricular planning stems from a decision of the Bologna Ministers (Bergen, 2005, see also Section 1 of the present Brochure)

1. INTRODUCTION TO THE TUNING PROJECT

Tuning Educational Structures in Europe is a university driven project, which aims to offer a concrete approach to implement the **Bologna Process** at the level of higher education institutions and subject areas. The Tuning approach consists of a methodology to (re-)design, develop, implement and evaluate study programmes for each of the Bologna cycles. It can be considered valid worldwide, since it has been tested in several continents and found fruitful.

Furthermore, Tuning serves as a platform for developing reference points at subject area level. These are relevant for making programmes of studies comparable, compatible and transparent. Reference points are expressed in terms of learning outcomes and competences. Learning outcomes are statements of what a learner is expected to know, understand and be able to demonstrate after completion of a learning experience. According to Tuning, learning outcomes are expressed in terms of the *level of competence* to be obtained by the learner. Competences represent a dynamic combination of cognitive and meta-cognitive skills, knowledge and understanding, interpersonal, intellectual and practical skills, and ethical values. Fostering these competences is the object of all educational programmes, which build on the patrimony of *knowledge and understanding* developed over a period of many centuries. Competences are developed in all course units and assessed at different stages of a programme. Some competences are subject-area related (specific to a field of study); others are generic (common to any degree course). It is normally the case that competence development proceeds in an integrated and cyclical manner throughout a programme. To make levels of learning comparable the subject area groups/Thematic Networks have developed cycle (level) descriptors, which are also expressed in terms of competences.

According to Tuning, the introduction of a three-cycle system implies a change from a staff centred approach to a student-oriented approach. It is the student that has to be prepared as well as possible for his or her future role in society. Therefore, Tuning has organized a Europe-wide consultation process including employers, graduates and academic staff / faculty to identify the most important competences that should be formed or developed in a degree programme. The outcome of this consultation process is reflected in the set of reference points – generic and subject specific competences – identified by each subject area.

Besides addressing the implementation of a three-cycle system, Tuning has given attention to the Europe-wide use of the student workload based European Credit Transfer and Accumulation System (ECTS). According to Tuning ECTS is not only a system for facilitating the mobility of students across Europe through credit accumulation and transfer; ECTS can also facilitate programme design and development, particularly with respect to coordinating and rationalising the demands made on students by concurrent course units. In other words, ECTS permits us to plan how best to use students' time to achieve the aims of the educational process, rather than considering teachers' time as a constraint and students' time as basically limitless. According to the Tuning approach credits can only be awarded when the learning outcomes have been met.

The use of the learning outcomes and competences approach might also imply changes regarding the teaching, learning and assessment methods, which are used in a programme. Tuning has identified approaches and best practices to form specific generic and subject specific competences.

Finally, Tuning has drawn attention to the role of quality in the process of designing or re-designing, developing and implementing study programmes. It has developed an approach for quality enhancement, which involves all elements of the learning chain. It has also developed a number of tools and has identified examples of good practice, which can help institutions to boost the quality of their study programmes.

Launched in 2000 and strongly supported, financially and morally, by the European Commission, the Tuning Project now includes the vast majority of the Bologna signatory countries.

The work of Tuning is fully recognized by all the countries and major players involved in the Bologna Process. At the Berlin Bologna follow-up conference, which took place in September 2003, degree programmes were identified as having a central role in the process. The conceptual framework on which the Berlin Communiqué is based is completely coherent with the Tuning approach. This is made evident by the language used, where the Ministers indicate that degrees should be described in terms of workload, level, learning outcomes, competences and profile.

As a sequel to the Berlin conference, the Bologna follow-up group has taken the initiative of developing an overarching *Framework for Qualifications of the European Higher Education Area* (EQF for HE), which, in concept and language, is in full agreement with the Tuning approach. This framework has been adopted at the Bergen Bologna follow-up conference of May 2005. The EQF for Higher Education has made use of the outcomes both of the Joint Quality Initiative (JQI) and of Tuning. The JQI, an informal group of higher education experts, produced a set of criteria to distinguish between the different cycles in a broad and general manner. These criteria are commonly known as the "*Dublin descriptors*". From the beginning, the JQI and the Tuning Project have been considered complementary. The JQI focuses on the comparability of cycles in general terms, whereas Tuning seeks to describe cycle degree programmes at the level of subject areas. An important aim of all three initiatives (EQF, JQI and Tuning) is to make European higher education more transparent. In this respect, the EQF is a major step forward because it gives guidance for the construction of national qualification frameworks based on learning outcomes and competences as well as on credits. We may also observe that there is a parallel between the EQF and Tuning with regard to the importance of initiating and maintaining a dialogue between higher education and society and the value of consultation -- in the case of the EQF with respect to higher education in general; in that of Tuning with respect to degree profiles.

In the summer of 2006 the European Commission launched a European Qualification Framework for Life Long Learning. Its objective is to encompass all types of learning in one overall framework. Although the concepts on which the EQF for Higher Education and the EQF for LLL are based differ, both are fully coherent with the Tuning approach. Like the other two, the LLL variant is based on the development of level of competences. From the Tuning perspective both initiatives have their value and their roles to play in the further development of a consistent European Education Area.

This brochure reflects the outcomes of the work done by the Subject Area Group (SAG) **of Physics** so far. The outcomes are presented in a template that was developed to facilitate readability and rapid comparison across the subject areas. The summary aims to provide, in a very succinct manner, the basic elements for a quick introduction into the subject area. It shows in synthesis the consensus reached by a subject area group after intense and lively discussions in the group. The more ample documents on which the template is based are also included in the brochure. They give a more detailed overview of the elaborations of the subject area groups.

The Tuning Management Committee

2. INTRODUCTION TO THE SUBJECT AREA

The body of knowledge, which is broadly named **physical sciences**, generates several degree-courses in the European Universities. Names such as

> *Physics, Astronomy, Theoretical Physics, Applied Physics, Engineering Physics, Biophysics, Physical Oceanography, Geophysics, Materials Sciences, Environmental Physics, etc.*

can easily be found. The *pure* degree-course is the **Physics degree-course**. In some of the above degree-courses, other subjects may be quite relevant together with physics, e.g. chemistry in Materials Sciences. All the above degrees always and heavily rely on a good mathematical background, which is offered, often since scratch, within the degree course itself. Continental universities traditionally offered to the Physics students a very deep and thorough approach to mathematics teaching/learning.

Physics is the most fundamental, after Mathematics, among the Natural Sciences and it describes within coherent logical frameworks the many facts of our surrounding physical world (whatever is their level of appearance, i.e. physics of the universe, earth physics, everyday classical physics, condensed matter physics, atomic physics, nuclear and particle physics) on the basis of reproducible experimental findings and of a deep knowledge of mathematics and mathematical tools.
Any physics graduate should then achieve great ability in both mathematical and experimental skills, which are really cornerstones at the heart of any physics learning path. Such competencies entail the development of several other both generic and subject specific competencies, which endow the graduate with a flexible mind, able to approach and model increasingly complex systems, even outside the realm of physical world. Indeed "physics provides an extraordinarily rich package of transferable skills"[3].
The Physics learning path is cumulative in itself: it identifies priorities and requires an ordered approach in the study progression. This is crucial not only in defining an entrance level for the first cycle[4] but also in the planning of the degree-course, which for successful progress requires development/achievement of specific knowledge and competences in both physics and mathematics.

An important aspect of the physics community is its international character, in both research and education, which suggests the need for physics students to be mobile during their learning path, almost compulsorily in the final cycles. Attending examinations, carrying out placements, enjoying research activity during project work or while preparing master thesis or doctoral dissertation, all these activities at a host university add true value to the achievement of the physicist's competencies and skills.

Finally and again in the words of the Validation Panel "physics is a subject where a large minority of graduates continues to study at the third cycle, probably more than any other subject. Despite that fact, the majority of physics graduates pursue jobs in industry, in the financial sector, in teaching etc.". As a consequence, most degree-courses which are offered by the universities of the Physics Tuning network are flexible enough "to accommodate both career routes", i.e. preparation both for a research career and for job market careers. Such a flexibility, however, establishes an important

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[3] See Physics Validation Panel Report, under "*Specific Questions*"
[4] Tuning has not yet explored this very important and extended issue, which strongly depends on country traditions in the secondary school organisation. The European Qualification Framework, in the form proposed by the European Commission, makes it urgent a study of this crucial interface "secondary school – university education". Tuning plans to enter this broad area in 2008.

criterion to be respected for a successful degree-course planning: its implementation may quite depend on national regulations.

When designing a Physics programme, two main approaches exist:

- The initial years of the programme are common to the subjects of physics, mathematics, chemistry, etc. and the students make the choice of the main subject only later (e.g. at the third year, this is the case of Copenhagen).
- The whole degree-course has “physics” as the key word.

Physics, being a natural science, is usually offered within the Faculty of Natural Sciences; this is the case of many continental universities. Another quite usual setting is the offer of the degree-course within a Physics Department, where the physicists’ community lives. In other cases the offer of a degree-course in Applied Physics or similar occurs within a Faculty of Engineering or a Department of Applied Physics. Moreover, and most important from the point of view of inter-disciplinarity, the physicists’ community often offers **units in Physics** for a number of quite different Degree-courses of the same university (see below).
The Tuning network in Physics reflects this complexity of scenarios. Nevertheless experience showed that meaningful common reference points can be obtained even with this apparently not homogeneous sample of institutions.

3. SUMMARY OF OUTCOMES

For a list of possible degrees, do see the introduction above. We give here the profile and occupations for the Physics Degree. The Degree-profile(s) should be taken as minimum requirements and not as absolute specifications. As an example, material from the second cycle might be taught at an earlier stage in some two-tier scheme (e. g. 4+1 with respect to 3+2).

3.1 – Degree profile(s) and occupations

Typical degrees offered in the subject area:

- First cycle in Physics
  - Knowledge of basic mathematics and related subjects (including mathematical methods for physics; computing; numerical analysis)
  - Knowledge of basic physics [introduction to physics; mechanics, vibrations and waves, acoustics, optics, thermodynamics, electromagnetism; quantum physics
  - Knowledge of experimental methods (asking the right questions, measurement theory and treatment of experimental errors, instrumentation,) and awareness about professional integrity
  - Knowledge of basic elements in theoretical physics (analytical mechanics; classical electromagnetism, relativity, etc.; quantum mechanics / theory; statistical physics)
  - Knowledge of elements of applied physics and related subjects (chemistry; electronics & related; etc.)
  - Knowledge of basic elements in modern physics (atomic, nuclear and particle physics, condensed matter physics, astrophysics)
  - Small *intermediate* or *final* physics project(s)
  - Other essential elements, in varying amount depending on the institution (e.g. Knowledge of specialised topics «*chosen from list(s)*»; presenting a lab report, taking active part in a seminar)
  - Some knowledge/abilities in non-standard subjects, in varying amount depending on the institution (e.g. vocational training, skills development, placement, etc.)
  - Knowledge of topics identified through a «*completely free choice*» of the student.

- Second cycle in Physics
  - Advanced knowledge of theoretical physics (analytical mechanics; classical electromagnetism, relativity, etc.; quantum mechanics / theory; statistical mechanics/physics)
  - Deep knowledge of mathematics and related subjects (advanced mathematical methods for physics; computing algorithms; advanced numerical analysis)
  - Knowledge of specialised core(s) of modern physics (atomic, nuclear and particle physics, condensed matter physics, astro-physics)

- Knowledge of experimental methods at advanced level (instrumentation, data analysis, experimental design, scientific methodology) and careful attention to matters related to professional integrity and honesty
- Ability to solve problems in comprehensive physics (depending on the institution)
- Final year physics project
- Other essential elements, in varying amount depending on the institution (e.g. Knowledge of advanced specialised topics «*chosen from list(s)*»; Ability to master advanced laboratory practice; Presenting a lab report; Taking active part in a seminar).
- Some knowledge/abilities in *non-standard subjects*, in varying amount depending on the institution (e.g. vocational training, skills development, placement, etc.)
- Knowledge of topics identified through a «*completely free choice*» of the student.

- Third cycle in Physics

- Coursework (depending on the institution, but in any case limited in time and at an advanced level) including courses on the development of professional skills for scientific research
- Original research in Physics in a research group at the home Department. The doctoral research *mostly* leads to a written dissertation, to be assessed by an appropriate Examination Board and/or to publications in refereed journals

<u>Typical occupations of the graduates in the subject area</u>

- First cycle in Physics

Sub discipline / Field of specialization	Category / Group of professions	List of professions related to specialization / category
PHYSICS	Physics bachelor	• Placements and positions in industrial companies • Informatics • Self employment
PHYSICS	General employment areas	• Management positions • Publishing positions • Banks • Insurance companies

- Second cycle in Physics (and Integrated[5] Degrees)

N.B. since the second cycle allows diversity in the specialisation fields of the final graduates, we list several sub-characterisation of the second cycle degree in Physics. In each sub-area the most relevant specific competences (not listed here, but see below in general) may have different weight.

Sub discipline / Field of specialization	Category / Group of professions	List of professions related to specialization / category
PHYSICS / EXPERIMENTAL PHYSICS	• Physicist • Physics engineer • Research and development related professions • Metrology /quality control related professions • IT[6] sector professions	• Researchers in universities, Institutes, industries. • Industrial placements and positions: microelectronics, software, telecommunications, opto-electronics, optics, materials • Banks • Insurance companies • Self employment • Technical consultancy
PHYSICS / THEORETICAL PHYSICS	• Physicists • Research and development related professions • IT sector professions	• Researchers in universities, Institutes, industries. • Industrial placements and positions: microelectronics, software development, telecommunications, optics, etc • Banks • Insurance companies • Self employment • Technical consultancy
ASTROPHYSICS	• Physicist • Astronomer	• Researcher and research assistant in universities, astronomical observatories • Industrial placements and positions: opto-electronics,

[5] *i.e.* a long one-tier first degree, without intermediate exit, replacing the two-tier degree scheme of Bachelor's plus Master's degrees.

[6] IT here stands for Information Technology

		optics, microelectronics, telecommunications
PHYSICS / TECHNICAL PHYSICS / PHYSICS ENGINEERING *sub disciplines*: – CONDENSED MATTER – APPLIED PHYSICS – ATOMIC AND SUBATOMIC PHYSICS – MATHEMATICAL PHYSICS – THEORETICAL PHYSICS	• Physicist • Physics engineer • Hospital physicist • Research and development related professions • Metrology / quality control related professions	• Research assistants in universities, Institutes, industries. • Industrial placements and positions: microelectronics, software, telecommunications, opto-electronics, optics, materials • Banks • Insurance companies • Self employment • Technical consultancy • Positions in Medical physics
PHYSICS / INFORMATICS PHYSICS	• Physics engineer • IT Sector professions	• Research assistants in universities, institutes, industries. • Positions in information technology sector, industry, banks, insurance companies, self-employed businesses • Technical consultancy
BIOPHYSICS	• Biophysicist • Biological Science researcher	• Researcher and research assistant in universities, institutes, industry • Positions in insurance companies, self-employed businesses • Technical consultancy
MEDICAL PHYSICS	• Medical Physicist	• Researcher and research assistant in universities, institutes, industry • Positions in Medical physics: hospitals, governmental institutions for medical care and health security • Positions in insurance companies, self-employed businesses • Technical consultancy
PHYSICS AND DIDACTICS or PHYSICS and a SECOND SUBJECT, at same academic level, plus DIDACTICS	• Physics Teachers *	• Physics teachers at Secondary and High Schools • Teachers in private organizations
PHYSICS / METEOROLOGY AND PHYSICS OF THE EARTH AND THE ENVIRONMENT	• Physicists in governmental organizations or private sector • Meteorologists	• Research assistants in universities, institutes, industries. • Meteorologists • Self employment • Technical consultancy
PHYSICS / OCEANOGRAPHY	• Physicists in governmental organizations or private sector • Oceanographers	• Research assistants in universities, Institutes, industries. • Oceanographers • Self employment • Technical consultancy

*The access to teacher qualification quite varies across Europe. In some countries teaching qualifications in Physics are obtained independently of the University physics degree. In some others Physics Teaching is a specialization of a physics degree or even a completely independent degree. So the situation described in the table is not universal. Moreover in such a situation it was not possible up to now to discuss and to come to an agreement about the minimum levels of skills and knowledge to be able to teach at secondary level. A precious first approach to the whole matter can be found in the recent Eurydice publication[7] *Science teaching in schools in Europe. Policies and research [reference year(s): 2004-05]*

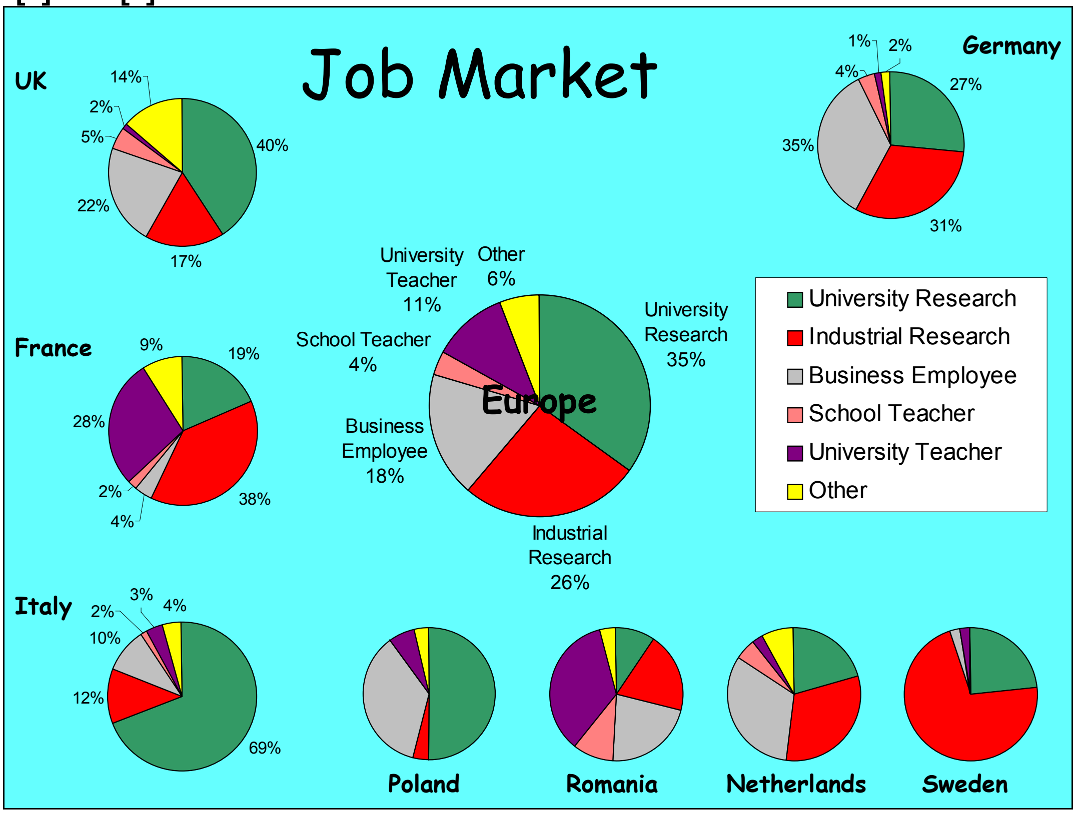
Third cycle

As suggested by many interviews, reports and personal experiences, what is mostly appreciated in physics graduates (not only the doctoral ones) is the *flexible mind*, i.e. the capacity to interpret and describe new situations, environments and problems on the basis of a wide experience of models and mathematical tools, as acquired by tackling physics problems. As a self-speaking

[7] See website http://www.eurydice.org/portal/page/portal/Eurydice/showPresentation?pubid=081EN, As reported therein "*This study focuses on science teaching in 30 European countries at primary and general lower secondary level. It provides a comparison of the regulations and official recommendations concerning initial teacher education: programme content and accreditation criteria, and the qualifications and experience of trainers in training establishments and in schools (for practical placement and final 'on-the-job' qualifying phase)*".

example we quote here the physicists, who work (in the banks and) in the stock-exchange agencies: on the wake of these fruitful experiences even a new discipline is taking shape at present, named *econo-physics* !. Another recognition comes from a recent survey, carried out in Portugal among master graduates and doctoral graduates, which shows that physicists turned out to be the third-best employable group after medical doctors and engineers(!?).
The results of the 1999 EUPEN survey about the first destination in the job market of the doctoral graduates are summarized in Fig.1 below, which is taken from Ref. [3]. Do notice, however, that the replies to this question might have often represented only an estimate of the respondent. It is difficult to collect this type of results on an European scale and that early effort is still a precious one.

Fig. 1 – The first destination of doctoral graduates in the job market, EUPEN survey, 1999, see ref. [1] and [3]



The pie-chart referring to the whole sample shows that – as an average – 46% of the doctoral graduates goes to "*university research*" and "*university teaching*", whereas 44% finds a job in industry or as a business employee and 4% goes to high school teaching. The remaining 6% could not be classified in one of the above-mentioned categories. The variations of these numbers with the country are (or rather were) quite evocative of the different cultural environments and traditions, in which doctoral graduates find their job. Take for instance the pie charts relating to the four most populated EU-countries: Germany, United Kingdom, France and Italy. All of them are quite different from the average one (the central pie chart in Fig. 2). The Italian graduates go mostly to "*university research*" (69% !). Such a percentage is still above average and still the majority percentage in the United Kingdom, but it is quite lower in Germany (27%) and France (19%). As to Germany, many of the graduates (35%) find a job as a "*business employee*", whereas this type of job is appropriate to the 10% only of the Italian graduates. Finally most French graduates go into "industrial research" (38%) and – in a relevant percentage (28%)– into "university teaching" too.

Other remarkable details are:

- The Swedish doctoral graduates find a job in industrial research in a very high percentage. Both DK and NO have pie-charts which resemble the Swedish one, while NL resembles the German one.

- The Polish first destination is at the University (as many as 58% go there!). The Romanian results referred in 1999 to a rapidly changing situation (the new organization after 1989 revolution) and today, i.e. 2006, they must be in any case updated, because of the Bologna reforms.
- In Greece as many as 25% of doctoral graduates entered "*secondary school teaching*" and as many as 15% were classified under "*other*" destination (mainly in the military service or going abroad for further study).

Role of subject area in other degree programmes

In many universities, the physicists' community offers units in Physics for a number of degree-courses, which are quite different from Physics. Indeed, Physics units are needed as an essential element for the degree-courses in mathematics, chemistry, geology, biology, etc.(all of them within the area of Natural Sciences), for all the degree-courses of the Engineering area and for several of the degree-courses of the faculties of Medicine, Veterinary Medicine, Agricultural Sciences, Pharmacology, etc.). Within this context different organisational models are at work. Possible – non exhaustive – examples are:

- the Physics Department serves all the many different interested degree-courses of the given university;
- the academics, who are physics teachers in other subject areas, belong to Departments, which are different from the Physics Department and are closely related to the subject of the degree course.

As an example, European wide meetings of the physics teachers for the Engineering area are convened regularly.

3.2 Learning outcomes and competences – level cycle descriptors

The basic knowledge of the field, i.e. the **relevant learning outcomes**, is described under Degree profile (see appropriate section above). Here we focus on competences and levels.

Generic competences in first and second cycle

The language of competences is the one easily understood by the job market. The Physics SAG participated in the early Tuning survey about generic competences, which was addressed to Physics graduates and their employers and later by the Academics. The survey was based on 30 generic competences, accurately selected by a group of experts. The average ranking of the generic competences by the Physics academics is shown below:

Ranking	GENERIC COMPETENCES
1	Basic Knowledge of the field
2	Capacity for Analysis and synthesis
3	Capacity to learn
3	Creativity
5	Applying knowledge in practice
6	Adaptability
6	Critical and self critical abilities
8	Basic knowledge of the profession
8	Research skills
10	Interdisciplinarity
11	Oral and written communication
12	Ethical commitment
12	Interpersonal skills
14	Knowledge of a second language
15	Elementary computing
15	Decision making

Apart from the results of the survey, which is four years old and which will be soon repeated, the Tuning Physics network quite agrees with the already quoted Validation Panel statement that “*physics provides an extraordinarily rich package of transferable skills*”. In more detail, the network believes that the following generic competences are of paramount importance in physics education:

- **Teamwork** and related special skills
- **Ethical commitment** from the point of view of both professional integrity and awareness of possible Physics social impact)
- **Capacity for analysis** and – separately – **Capacity for synthesis**
- **Appreciation of the mobility experience,** which make the exchange student open-minded, able to adapt and aware of the physics international character (as far as possible already within the first cycle)
- **Learning to gather relevant information**, not only when researching but also in a lifelong learning perspective.
- **Good working knowledge of the English language**
- **Communication skills** in order to communicate the very difficult concepts of Physics to a wide range of audiences (peer groups, decision makers, children and the general public). An important related methodology, to be linked to some form of assessment, is promoting occasions on which students – as an essential part of their learning path – talk to each other about physics.

We finally underline the fact that these competencies “should be embedded, so far as possible, into the teaching of physics”[8]. We also underline that they become fruitful only on the basis of a deep knowledge (see Section 3.1) and understanding of the subject area.

Subject specific competences for the two first cycles

The Physics specific competences for the first two cycle were identified by the Physics SAG in co-operation with the EUPEN Thematic Network. They are 22 in number and are listed in Section 4 below, under both a short name and an extended description. In the following two tables we present the order of importance of these competences respectively in the first and in the second cycle, as rated by the academics. Only short names are used in the tables and only the best rated competences in each cycle. The physics related competences are further classified as (see the two tables):

- cognitive abilities and competencies
- practical skills
- additional generic competencies.

In each cycle table for each competence we also show its related Dublin Descriptor dimension, through an appropriate code (see box below). The order describes the (decreasing) importance of the competence in the given cycle according the judgement (or *rating*) of a selected group of European physics' academics (about 120 in number, see ref. [8]).

Dublin Descriptors levels and codes (*see ref [10]) : for each Bologna cycle – i.e. bachelor, master, doctoral cycle – the Dublin Descriptors define through appropriate general statements the level to be achieved by the student in the degree-course specific competencies. The cycle statements refer to five basic « dimensions », which are assumed to cover all possible competencies. As a whole we then have 3 cycles x 5 dimensions = 15 Dublin Descriptors (as a matter of fact, they are 16, since in the doctoral cycle two statements refer to one out of the 5 « dimension »).*

The cycle identifies the level to be achieved :

CYCLE	***LEVEL DESCRIPTION***
1st (bachelor)	(includes) some aspects of forefront knowledge (of their field)
2nd (master)	(provides) basis (or opportunity) for originality
3rd (doctoral)	(contributes through) original research (that extends front of knowledge)

The codes for the dimension are :

CODE	***DIMENSION***
A	Knowledge and understanding
B	Applying knowledge and understanding
C	Making judgements
D	Communications skills
E	Learning skills

As a conclusion a given competence is characterised by a level of development [read CYCLE] and by its appropriate dimension(s) [read CODE].

[8] from the Written Report of the Validation Panel

The competences' distribution over the five "dimensions" of the Dublin Descriptors gives an idea of relative weight of each dimension in a cycle. The tables follow in the next page. Do notice the quite different distribution pattern in the two cycles.

First cycle

"Rating of importance order"	Physics-related cognitive abilities and competencies	Physics-related practical skills	Physics-related additional generic competencies	RELATED DUBLIN DESCRIPTOR
1	Estimation skills			A
2		Mathematical skills		A-B
3	Deep knowledge & understanding			A-D
4		Experimental skill		B
5		Problem solving		A-B
6	Modelling skills			B
7	Physics culture			A-D
8	Familiarity with Basic & Applied Research			A-B-C
9			Literature search skills	E
10			Learning ability	E
11	Human / professional skills			A-B
12	Absolute standards awareness			A-C
13			Ethical awareness (relevant to physics)	C
14			Foreign Language skills (relevant to physics)	E
15			Specific Communication Skills	D

- Second cycle

"Rating of importance order"	Physics-related cognitive abilities and competencies	Physics-related practical skills	Physics-related generic competencies	RELATED DUBLIN DESCRIPTOR
1	Modelling skills			B
2	Estimation skills			A
3			Literature search skills	E
4			Learning ability	E
5	Deep knowledge & understanding			A-D
6	familiarity with Basic & Applied Research			A-B-C
7		Mathematical skills		A-B
8	Frontier research			A
9		Problem solving		B
10		Experimental skills		B
11			Specific Communication Skills	D
12			Managing skills	C
13			Human / professional skills	A-B-C
14	Physics culture			A-D
15			Updating skills	E
16			Foreign Language skills (relevant to physics)	E
17			Ethical awareness (relevant to physics)	C
18			Absolute standards awareness	A-C

Further remarks about levels:

Many subject specific competences appear both in the 1st and 2nd cycle. However, their level of development and their order (i.e. importance) is different. Each cycle is characterised by its own priorities, too. Indeed, most of the 7 best competences of the 1st cycle (i.e. except "*Estimation skills*" and "*Problem Solving*") fall behind in the 2nd cycle ordering. In other words the skills, which are most important in the first degree, become somewhat less important in the 2nd cycle. In particular *Physics culture* is most important in the first cycle only; some others – *Frontier research*, *Specific Communication Skills*, *Managing skills* and *Updating skills* – are quite relevant in the second cycle only.

For a given competence, the actual *average* rating value in the 1st cycle (not shown here, see ref [8]) is always lower than in the 2nd cycle. Such lower values witness the fact that the competence development is a cumulative process and – moreover – confirm the idea that in a given "dimension" the Dublin Descriptors shows the level of development appropriate to the cycle. In fact, the rating *gap* across the two cycles can be taken as a "rough" measure of the further development, which has to be achieved in the 2nd cycle. Among the "Physics competences" the highest gaps are scored (in decreasing order) by *Frontier research*, *Managing skills*, *Specific Communication Skills*, *Modelling*, *Updating skills*, *Ability to learn, Literature search*. The lowest gaps are scored by *Absolute standards*, *Theoretical understanding*, *Physics culture*, *Mathematical skills*, *Estimation skills*[9] (minimum gap). The highest gaps identify competences, which are appropriate at 2nd cycle level, and small gaps identify competences, which should be already well developed in the 1st cycle.

Finally, our analysis shows that identification of a *common* core knowledge is certainly possible in Europe in the 1st cycle degree courses in Physics, but it becomes rather questionable in the 2nd cycle, essentially because each institution focus on a different specialisation (see Fig 2 at page 197 of Ref [7]). The common core knowledge of the 1st cycle is quite similar everywhere and shows a time-progression pattern, which is governed by the requirements needed to progress in the subject knowledge. Some variation occurs between the two main existing methodological approaches (i.e. synthetic or British and analytical or continental approach).

Trends and differences:

In the year 2002 the Tuning Network included two groups of institutions, almost equal in number:

- Institutions with a "Bachelors – Masters (BaMa)" organisation of studies (i.e. a two-cycle organisation, mostly according to a "3+2" scheme). The institutions were: Kobenhavn, Granada, Nijmegen, Paris VI, Trieste, Dublin City University and Patras (which adopted a "4+2" scheme).

- Institutions, which offer an Integrated Masters level degree course (i.e. a single cycle organisation, without an intermediate exit after 3 years). The institutions were: Gent, Göteborg, Chalmers University of Technology, Helsinki (Physics), Imperial College London, Aveiro, Hannover, Technical University Wien.

The *common core content* was practically the same in the two groups (see Fig 3 at page 197 of Ref [7]). Do remind that in the case of a two-cycle organisation of studies, the identification of a common core content is quite feasible in the 1st cycle, but it becomes questionable in the 2nd cycle (see right above). Within such a scenario it is a must to recognize that student mobility (either exchange or cycle to-cycle, i.e. vertical, mobility) can fruitfully occur to the benefit of the moving "scholars". Furthermore each Physics Department may and can plan strategic alliances, focusing on complementary teaching and research resources among partners.

[9] NB important for those who want to look at ref. [8] for more details: the present short name *Estimation skills* replaces the former short name used there *Problem solving (skills)*. Similarly the present short name *Problem solving* replaces the former short name used there *Problem solving & computer skills.* Moreover the present short name *Deep knowledge & understanding* groups together the two short names used there *Deep knowledge* and *theoretical understanding.* Similarly the present short name *Modelling* groups together the two short names used there *Modelling & Prob. Solv.* and *Modelling*.

Consultation process with stakeholders

The Tuning consultations among the Physics graduates (mostly in the pre-Bologna period) and their employers gave the following ranking of the generic competences (we list the first five competences only):

graduates	employers
Capacity for analysis and synthesis	Capacity for analysis and synthesis
Problem solving	Problem solving
Capacity to learn	Capacity to learn
applying knowledge in practice	applying knowledge in practice
Creativity	Teamwork

The results of the two consultations are strikingly similar. Compare with the Academics ranking given above (the Academics' questionnaire however didn't include the generic skill "*problem solving*"). A full description of these results is given in Ref. [6].

- Third cycle (subject specific and generic)

The third cycle outcomes: a more complex scenario

The third cycle has its own specificity with respect to first and second cycle, since the doctoral candidates are at the same time "students and early stage researchers" (Bergen Communiqué, 2005). According to the Physics SAG then the third cycle should be characterized by "process outcomes", which are comprehensive of both "learning outcomes" (to be reserved for coursework and skills) and "research outcomes". These latter ones are in general the research results themselves, the thesis report and the published papers. Intellectual property rights may play an important role, too. Other research outcomes are delivered by those doctoral research projects, which – being experimental ones (including applied physics) – may yield different kinds of spin-offs and patents.
On the other hand, also the generic competences, which can be achieved through doctoral training, are sometimes at a different level (more refined) than those needed/developed in the two lower cycles. We give examples below.

Learning Outcomes in a Physics doctoral programme

Of course the single learning outcome "be deeply familiar with the subject of the thesis research work" is also relevant, but it varies strongly, being closely linked to the actual doctoral research work. In general terms the learning outcomes should then be limited to the coursework part of the doctoral training. The planning of the doctoral course-work units should take decisions about the following issues:

Should the coursework

i. be addressed to a generalist type of preparation, filling the main "cultural" gaps of the candidate's previous preparation?
ii. be of a specialist type, in order to favor a better immersion in the future doctoral research work?
iii. offer the basic elements of the other subject(s), in the case of future interdisciplinary research work of the doctoral candidate and at which level should be this latter offer taught/learned?
iv. offer some help in developing specific research abilities or methodologies, to be used later or even to be known for the sake of a cultural completeness (e.g. experimental techniques appropriate to a given field or subfield to be known by a candidate, who will later engage in theoretical research work)?
v. devote attention to the development of generic skills?

level descriptors for the third cycle

a) The validity of the Dublin Descriptors

According to the Physics SAG, the first and main descriptor of a doctoral cycle is

"*to be able to do research in the field of Physics*".

Then most of the Dublin Descriptors for the 3rd cycle express in a very good way the different facets of the Physics research abilities, provided the words "field of study" are substituted by the word "physics" in the first statement and the words "frontier of knowledge" with the words "frontier of physics knowledge" in the third statement. Indeed, the Dublin Descriptors for the third cycle are at the same time *general enough* to cover all the many possible physics sub-areas, which are the object of the doctoral research activity, and *specific enough* to cover the main aspects of the research activity in a hard science like physics. It is also felt that some descriptors are more relevant than others: the last two in particular may be of secondary importance, when evaluating the doctoral research work.
Such research-based competences are clearly different from those, which are relevant in the two lower cycles.

b) The Physics specific competences

Moreover the Physics SAG identified the following specific competences, which have to be achieved by physics doctoral graduates. They may vary in their relative weight, depending on the type of doctoral thesis, e.g. whether it involves an experimental or a theoretical work. Moreover it may depend on the particular research issue. A preliminary list is given here below; their detailed description is given in the following Section 4. We identified as relevand third cycle Physics specific competences: .

modelling abilities,
phenomenological abilities,
flexible mind skills,
physics methodology skills;

Some competences are most important for theoretical research work. They can be described in terms of ***theoretician's skills***.

Some competences are most important for experimental research work. They can be described in terms of ***experimentalist's skills.***

Finally, the Physics SAG quotes a generic but most specifically crucial competence, i.e.

fund raising and general awareness of financial matters (including ability to present a grant application, attention to intellectual property, patents and technology transfer).

c) "crucial" generic competences and doctoral mobility

Since the doctoral candidates are increasingly required to develop the so-called *transferable skills* during their doctoral studies, we give here a list of generic skills, which was recently identified by the Coimbra Group network of historical universities, in view of a summer school – in year 2007 – for training of doctoral candidates from the Group. The identified important generic skills are[10] "*personal effectiveness, time management, teamwork, networking, professional ethics, communication and presentation skills, assertiveness, negotiation skills, writing skills, media communication, intellectual property management, commercialization of research, information retrieval, thesis writing, career planning, and so on. Most of these skills are not directly related to the research field of the individual student and are therefore amenable to cross-disciplinary training*".
Other important generic skills are suggested by the inspiring ref. [9], a background document commissioned by the Magna Charta Observatory. We report here the three synthetic definitions (the actual text of ref. [9] is between quotation marks):

"***capacity of problem choice and solution***", i.e. the candidates should be able "to find, select and define problems of interest that can also be solved in a reasonable timeframe".

*"**capacity to walk their own line**",* i.e. the candidates should be able to balance the achievement of their own personal skills and research outcomes with their contribution to more collective research enterprise. "This means finding an

[10] From the presentation letter of the chair of the Coimbra Group Executive Board (2006).

equilibrium between their own time (as taken to develop high quality knowledge) and the overall time economy that *shapes university research* as a field of intellectual quest".

*"**capacity to reflect upon the questions they (i.e. the candidates) raise, the types of knowledge they produce and increasingly also on the impact their knowledge might have on society**"*, i.e. the candidates should be able to practice "a critical distance to one's own work". This competence seems crucial in "building the ground for a sustained relationship of mutual trust between the scientists and the citizens". In this latter respect good ***communication skills*** are quite relevant, too (see also the initial paragraphs of this same section).

We end this section by reminding that mobility of doctoral candidates is an essential ingredient to shape their competences. Indeed a special point in the *European Charter for Researchers and on a Code of Conduct for the Recruitment of Researchers* recommends the value of mobility in the "training" of researchers[11]; mobility may be *"geographical, intersectoral, inter- and trans-disciplinary and virtual (i.e. remote collaboration over electronic networks) mobility, as well as mobility between the public and private sector".*

4. LIST OF SUBJECT SPECIFIC COMPETENCES (annex to previous Section 3)

This section deals with definitions only. They are slightly different from those used in Ref. [8]; see also footnote 5.

- First and second cycle (in alphabetical order of Short Name)

Short Name of the Physics Specific Competences	**Extended Description of the Physics Specific Competences** *on completion of a degree in Physics, at the level appropriate for first (bachelor) or second (master) cycle, the student should:*
Ability to learn	Be able to enter new fields through independent study
Absolute standards awareness	Have become familiar with "*the work of genius*", i.e. with the variety and delight of physical discoveries and theories, thus developing an awareness of the highest standards
Applied jobs (lower level positions, e.g. accessible after a first cycle degree)	Be able to carry out the following activities: professional activities in the frame of applied technologies, both at industrial and laboratory level, related in general to physics and, in particular, to radio-protection; tele-communication; tele-sensing; remote control with satellite; quality control; participating in the activities of the public and private research centres (including management); taking care of analysis and modelling issues and of the involved physics and computer aspects
Deep knowledge & understanding	have a good understanding of the most important physical theories (logical and mathematical structure, experimental support, described physical phenomena), including a deep knowledge of the foundations of modern physics, say quantum theory, etc .
Ethical awareness (relevant to physics)	Be able to understand the socially related problems that confront the profession and to comprehend the ethical characteristics of research and of the professional activity in physics (professional integrity) and its responsibility to protect public health and the environment
Estimation skills	be able to evaluate clearly the orders of magnitude in situations which are physically different, but show analogies, thus allowing the use of known solutions in new problems; be able to appreciate the significance of the results
Experimental skills	be able to perform experiments independently, as well as to describe, analyze and critically evaluate experimental data and have become familiar with most important experimental methods
Familiarity with Basic & Applied Research	have acquired an understanding of the nature and ways of physics research and of how physics research is applicable to many fields other than physics, e.g. engineering; be able to design experimental and/or theoretical procedures for: (i) solving current problems in academic or industrial research; (ii) improving the existing results

[11] Data relating to the mobility of the doctoral candidates are available locally at institutional level and in some official reports. The general conclusion is that at doctoral level spontaneous mobility is much more frequent than the organized mobility (i.e. organized within official programmes).

Familiarity with frontier research	Have a good knowledge of the state of the art in - at least - one of the presently active physics specialities
Foreign Language skills (relevant to physics)	Have improved command of foreign languages through participation in courses taught in foreign language: i.e. study abroad via mobility/exchange programmes, and recognition of credits at foreign universities or research centres
General Jobs (high level positions, in which a physicist may profitably perform)	Be able to carry out the following activities: promoting and developing scientific and technological innovation; planning and management of technologies related to physics, in sectors such as industry, environment, health, cultural heritage, public administration; banking; high level popularisation of scientific culture issues, with emphasis on theoretical, experimental and applied aspects of classical and modern physics.
Human/professional skills	be able to develop a personal sense of responsibility, given the free choice of elective/optional courses; be able to gain professional flexibility through the wide spectrum of scientific techniques offered in the curriculum
Inter-disciplinary attitude / abilities	Acquire additional qualifications for career, through optional units other than physics
Literature search skills	be able to search for and use physical and other technical literature, as well as any other sources of information relevant to research work and technical project development. Good knowledge of technical English as well as on-line computer searching skills are required too.
Managing skills	be able to work with a high degree of autonomy, even accepting responsibilities in project planning and in the managing of structures
Mathematical skills	be able to understand and master the use of the most commonly used mathematical and numerical methods
Modeling skills	(a) be able to identify the essentials of a process / situation and to set up a working model of the same; (b) be able to perform the required approximations; i.e. critical thinking to construct physical models; (c) be able to adapt available models to new experimental data
Physics culture	be familiar with the most important areas of physics and with those approaches, which span many areas in physics
Problem solving	be able to perform calculations independently, even when a small PC or a large computer is needed, including capacity[12] to utilize or develop computation systems or programmes for information processing, numerical calculus, simulation of physical processes, or control of experiments
Specific communication skills	be able to present one's own research or literature search results to professional as well as to lay audiences (orally and in written form to describe complex phenomena/problems in everyday language, as appropriate to the audience); be able to work in an interdisciplinary team
Specific updating skills	Enjoy facility to remain informed of new developments and methods and be able to provide professional advice on their possible range of applications
Teaching ability	Be prepared to compete for secondary school teaching positions in physics

- Third cycle Physics specific competences

(i) ***phenomenological abilities***, i.e. being able to organize a number of relevant facts in a coherent framework, based on physics knowledge.

(ii) ***modeling abilities,*** i.e. being able of
- setting up and testing a model,
- comparing different models among themselves (advantages / disadvantages)
- comparing the model with the physical world or with the phenomenology, which the model tries to explain
- numerically simulating a given set of experimental facts (including the critical use of existing computer codes)
- using mathematical and computational skills in the context of model testing and validation.

(iii) ***physics methodology skills***, i.e. being *familiar with*, being *able to apply the scientific method through*

[12] We gratefully acknowledge the Tuning Latin America Subject Area Group for offering this excellent definition (see Tuning Document for the Validation Conference of the Natural Sciences in Tuning at page 171).

- putting the right questions to the external world
- collecting the answers and identifying the reproducible experimental facts
- translating the experimental facts into a model ("theory"), which include all important factors
- trying and trying again
- being able to criticize the model, in order to set up a new one.

(iv) ***flexible mind skills***, i.e. being able to apply the acquired knowledge and understanding in different contexts (e.g. from physical to economical contexts) and to be able to innovate (with new concepts or mathematical tool or…) whenever appropriate.

(v) ***theoretician skills****,* i.e. familiarity with and/or mastering of:

- mathematical theories
- analytical and numerical methods
- main physical theories

(vi) ***experimentalist's skills****:* familiarity with and/or mastering of:

- technology related to the research work activity
- Information technology and electronics
- the technological process: from conceptions to spin-offs
- project and personnel management (mainly in complex experimental projects, which often involve many people)

(vii) ***fund raising and general awareness in financial matters***, i.e. a competence, which is becoming more and more important in research groups. Some initiation to this ability must be tried also during the doctoral period (e.g. writing a research grant application, dealing with inellectual property rights' issues, patents, etc.).

5. BACKGROUND PAPERS REGARDING THE REFERENCE POINTS OF PHYSICS

The Tuning work was profitably inserted on the previous experience of the EUPEN – EUropean Physics Education Network, which already provided some common background to the Physics SAG members. The details of the Tuning work are given in two main papers published in the first Tuning book (2003).

The first paper, see Ref. [7], deals with the operational definition of the *core subject knowledge*, which is to be achieved in a Physics curriculum. With reference to different possible settings (institutional, national, European-wide), we identified the variables which may characterize a core curriculum. The essential elements are:

- core contents;
- a set of organisational elements, which are not directly related to content, e.g. choice(s) from list(s), completely free choice, final project/thesis work, other essential elements (e.g. comprehensive exam(s); intermediate project work; compulsory seminar; compulsory placement, etc.).

In the subsequent Tuning consultation, we identified 17 content items and 10 (other) essential elements. These results allowed identifying the Learning outcomes, which are appropriate to a Physics degree course (see Section 3.1 above, under Degree profile; see also in Section 3.2 the paragraph "Further remarks about levels").
A final interesting number from the consultation relates to the *average* core content, which was as high as 76% as a percentage over the total in the first cycle and "only" 34% in the second cycle.

A second paper, see Ref. [8], describes the European academics' evaluation of the Physics specific competencies for the first and second cycle (see Section 4 above for definitions). Many interesting conclusions stem from this second wider consultation. Some of them are reported in Section 3.2 above, again under the paragraph "Further remarks about levels". Do see also the following Section 6 for examples about how to develop these competencies in the learning path. Here we only report the main conclusion, i.e. the fact that the Physics academics identified as "signature" competences for Physics the competences whose short names are Estimation Skills, Problem Solving and Modelling. In agreement with the Validation Panel Report we emphasize here that "training and exercises need to be in the context of a deep understanding of physics; it is insufficient – for example - just to have the mathematics without the physical intuition".

6. APPROACHES TO TEACHING, LEARNING, ASSESSMENT USED IN PHYSICS

6.1- INTRODUCTION

The SAG work aimed at identifying concrete ways through which the Tuning Physics-related competences (see Section 3 and 4) could be developed in the students, who are attending a Physics degree-course at their institutions. On the other hand, the Physics SAG could also rely on some previous work in the field made by the EUPEN Socrates TNP, co-ordinated by the University of Gent under the supervision of Prof Hendrik Ferdinande (see ref [4]). Indeed already in 1997-98 the need for a characterisation of the teaching/learning styles in the different European educational systems was clearly perceived by EUPEN. A questionnaire was prepared with 21 (groups of) questions, either multiple choice questions or very simple questions. The questionnaire was sent to the key contact persons in 19 institutions of the EUPEN network, each one *representing* a country. The questionnaire included questions, which related to two broad classes of variables:

- the "organisational variables"
- the "teaching style variables".

A complete report can be found in the already quoted Ref [4]. A general conclusion of the EUPEN survey was that each institution develops its own route to physics education, by grading in many ways the use of the different organisational and educational tools. So it seemed hopeless to catalogue the different approaches into a limited number of "models" (as it was hoped for). We sketch here the methodological approach and only some of the findings, those thought to be more relevant to our attempt of giving a coherent framework to the subsequent Tuning work.

6.2- THE ORGANISATIONAL AND QUALITATIVE VARIABLES

– The organisational variables

The main organisational degrees of freedom relate to:

- co-ordination in contents of the different course units in the degree-course: at either national or local level.
- patterns of control of the student's progress of studies, (entrance selection, free choice of exam date, progress control either by the student good will or by the institution, selectivity of the degree-course, overrun);
- student assessment of teaching.

– The qualitative variables

The EUPEN questionnaire was sent out in the pre-Tuning age. For this very reason its findings must be taken only as a characterisation of the "*humus*", i.e. the breeding ground, where the Tuning process can nowadays display its reflection potential and its development action.

The main qualitative characterisations of a given teaching approach stem from choices or consolidated educational traditions regarding:

- "formative *versus* factual" degree course: i.e. "*Can the degree course at your university be characterised as formative (i.e. based on ideas, methods, understanding) or rather as factual (i.e. based on factual knowledge of scientific information?)*". Perhaps in the "Tuning language" this question would become "*Is the degree* *course at your university reflecting a competence based approach or rather does it privilege contents and facts?* ";

- ways of lecturing, i.e. whether the lectures are offering a *detailed and thorough mathematical treatment* or rather are based on *survey, understanding by examples and simplified models*"[13]. Do notice that the adopted pattern possibly affects the type of academic work done by students, during their private study time (see below). Even though the results described in the present paragraph refer to a pre-Bologna period, nevertheless they witness clear-cut educational traditions;

- organisation of laboratory classes (broadly speaking *cookbook recipes* and/or *detailed instructions* versus *creative student commitment*);

- student's contact with the research environment;

- problem solving classes ("passive" listening versus "active" involvement of the student; "quick" problem solving, rather than "in-depth" problem solving; integrated problem solving classes, i.e. *comprehensive* exam preparation);

- "academic" or "open to civil society" teaching approach;

- Ways of examinations: *exam date* fixed by the institution, as a single deadline, or a freely chosen; *exam type*, i.e. (i) multiple choice questions; (ii) discussion of general concepts; (iii) thorough and analytical treatment of the subject; (iv) problem solving; (v) other types of examinations; *oral* versus *written* examinations. A clear correlation exists between the way in which examinations are taken (written or oral) and the type of examinations (as described right above). Exams mostly consist of problem solving, in those institutions where written assessment is used; on the contrary they consist of a thorough and detailed treatment of the subject, when an oral approach is preferred. In the latter cases, we have testimony that it may take as much as one third of the student homework to memorise formulas, mathematical steps etc., once the concepts have been understood by the student.

In this very context a comparison with the type of "private" academic work done by the students during the exam preparation weeks is enlightening! Indeed, qualitative characterisations of the teaching offer – such as *types* of examination or *ways* of lecturing (see above) – have a remarkable consequence on the learning style of the students. This very aspect was investigated through an adequate and simple EUPEN questionnaire (1998, see again Ref. [4]). The students were asked to state how the hours, which they spent in a week on private study, broke down into the following types of academic work:

(i) *Preparing reports on laboratory work*
(ii) *Working on problem sheets or assignments*
(iii) *Studying lecture notes*
(iv) *Studying text books or other course books*
(v) *Background reading and essay writing*
(vi) *Learning a foreign language*
(vii) *Course related computing.*

The results showed that the students of those institutions, where the ways of lecturing quite privilege *detailed and thorough mathematical treatment* (first pattern, e.g. in AT, IT) and where the exam is mostly based on a *thorough and detailed treatment* of the subject (being an oral examination), spent most of their private study time on *Studying lecture notes* and *Studying text books or other course books*. On the contrary, in those institutions where the way of lecturing is based on "*survey, example understanding, models*" (second pattern, e.g. in GB) and where the exam is mostly based on *general concepts* and written *problem solving*, the students distributed their private study time more or less evenly through the seven types of academic work listed above.

– A preliminary conclusion

As a conclusion, the answers to the EUPEN early questionnaire are quite informative about a large range of existing behaviours: some of these behaviours have a striking impact on the student practices in the private study part of their career.

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[13] In the Tuning language, this question might become "*does your degree-course privilege the development of mathematical competencies and of analytical deep understanding of the subject or does it rather focus on modelling skills and subject specific problem solving*".

6.3 - Developing The Tuning Physics-Related Competences

6.3.1 – Overview

A richness of teaching /learning styles emerges also from the Tuning work, which was carried out by the SAG members in view of the Athens meeting ("Athens homework", November 2003). In this Section we try an homogeneous description of how some of the Tuning Physics-related competences (see complete list in Section 4 above) may be developed through teaching methodologies, understood by the students and achieved through their own commitment and finally how they may be assessed. Our general idea is to assemble a kind of inspiring handbook on specific competences, to be used by the Tuning community and possibly by a wider European audience as common reference points in curricular planning or revising. Because of the way, in which our Tuning work was organised, 6 out of these 13 competences were reviewed with reference to the first cycle and the remaining 7 ones with reference to the second cycle.

As fully explained in Section 3 above, the Physics SAG identified a set of subject specific competences, which are the descriptors for both the first and second cycle. The most preferred competences in each cycle (out of a total of 22 identified ones) are shown in the two Tables of Section 3 above.

In the following Matrix Table we show the *educational activities*, which are thought to be appropriate to the development of each of the 13 above *competences*, by ticking with the figure "**1**" the box at the crossing of the corresponding column and row, on the basis of the answers to the Athens homework. The Table can be examined with reference both to its rows (i.e. 26 different educational activities as emerging from the Tuning work[14]) and columns (i.e. "our" 13 subject related competences). The last column shows how many competences out of the 13 ones can be developed under a given educational activity. The last row, on the other hand, shows how many out of the identified educational activities contribute to the development of a given specific competence.

It is then clear, from the point of view of educational activities, that some of them – e.g. (active) problem solving classes, lab and practical classes, project work (including master thesis) and even lectures – are *holistic,* in the sense that they develop many subject specific competences at a time. Other activities are more adapt to develop a single or a limited number of specific competences (e.g. lectures with demonstrations, scientific writing class, numerical calculation & computing class, individual activity in a class, etc.).

On the other hand, from the perspective of competences, there is a group of competences, whose development occurs transversally to *all* or *almost all* existing educational activities, while a second group includes competences, which are developed mainly through a restricted set of well defined activities. Competences like *Estimation skills*, *Mathematical skills*, *Modeling*, *Physics culture* clearly belong to the first group (transversal specific competences). Competences like *Frontier research*, *Experimental skills* (!) and *Managing skills* are definitely in the second group. These latter competences, depending on the greater or lesser attention paid to them and/or on the performance achieved in them by the students, may differentiate the graduates' final preparation and expectations (e.g. graduates who feel like becoming a researcher, an experimental physicist, a manager physicist, etc).

This latter remark recalls an important aspect, i.e. the existence of competences, which are more directly linked to the contents/specialisations offered within the degree-course. While at the first cycle level most institutions offer a generalist approach to physics contents (i.e. the graduate has to achieve a general background preparation, see the competence *physics culture* below, in the second cycle usually many different content options are offered, yielding a final graduate who then has a "specialised" competence (e.g. knowledge either in nuclear physics or in condensed matter physics or in bio-physics or in astro-physics and/or astronomy, etc.), only seldom achieving a really generalist preparation.

[14] Do notice that the listed activities are 27 indeed, but that one of them, i.e. *(passive) problem solving classes*, is not quoted in the Athens homework. This is good for Tuning! Nevertheless it is included here, since the previous EUPEN consultation (see Section 6.1 above and ref. [4]) found that it exists and that it is more or less used, probably depending on the teacher's habits and local traditions.

MATRIX TABLE : Main educational activities for Physics students ***versus*** **subject specific competences –** ***a possible simple example***

[redacted]

From the Table it is also clear, and this is often stressed in the answers contained in the Athens homework, that the development of specific competences is a complex cumulative process, which lasts for the whole degree course (and even beyond in real life!). Such a development is very similar in its nature and dynamics to the development of generic skills.

In the following we report for each of the above 13 competences:

- The short name, with a number indicating the ranking by the academics, see the Tables for first and second cycle in Section 3;
- The Tuning definition (for an easy readability),
- Interesting aspects concerning the teaching strategies, the students' committment and the assessment procedures, as extracted from the Athens homework exercises, carried out by the SAG members. As far as possible sentences taken from the homework exercises are quoted in *arial italics* characters.

6.3.2 – Physics Subject Related Competences – First Cycle

Estimation Skills [1]

Definition: be able to evaluate clearly the orders of magnitude in situations which are physically different, but show analogies, thus allowing the use of known solutions in new problems; be able to appreciate the significance of the results

Important premise

In order to develop this competence an obvious pre-requirement is to have theoretical and practical knowledge, gained in specific course units.

Many first-cycle students think that *training in this competence* is the same as *exercise solving* and do not understand those teachers, who insist in giving them assignments, that need mastering more complex reasoning or cross-disciplinary knowledge. Students in the last stage of the degree-course do not show this kind of problem.

Teaching/learning

Example 1

"*This competence is mainly developed through assigning the students many examples of problems to solve. Some of these are assigned as 'homework' but others are set in real time mainly in tutorials. The cooperative development of solutions in tutorials is the most important method. This involves a great deal of 'to-and-fro', trial and error etc. rather than following standard techniques. There are also special problem solving classes which involve students attempting problems themselves but with immediate help on hand from academic staff and PhD students. Special tutorials are arranged in the 3rd or 4th years for realistic problem solving (comprehensive problems)".*

Example 2

The exercise class sessions are organised as follows:

- *Problems to be solved on the spot. During a course unit problems are usually given with a gradual increase in difficulty, in the perspective of increasing independence of the student, i.e. thorough cooking recipes get gradually replaced by fewer and fewer hints.*
- *Home work problems to be discussed in the exercise class, after the home work is handed in and graded.*

Example 3

Active Learning: in all classes (theory, lab or problem solving)

- *Several questions are posed to the theory class and a certain amount of time is allowed for discussion in the same class.*
- *Several question-problems are set to the class and assigned to groups of students. They should find an answer (either exact or approximate) in a certain amount of time. They are also requested to explain their reasoning to other students (Did they divide the problem in simpler problems? did they use analogies with problems, for which they already knew the answer? why are they confident about their own answer?…)*
- *In the exercise classes the students are requested to correct and comment other students ways of solving the exercises.*
- *In the lab classes students are frequently asked to solve experimentally or propose ways for solving other more complex problems that may be considered extensions of the material proposed in the class. (ex: after studying an LC circuit they are encouraged to solve the problem of coupled LC circuits and think about the problem of impedance adaptation in a transmission line).*

Assessment

The main assessment procedures of the present competence span the whole degree-course and involve: end of year examination marks; performance in problem solving classes; marks for assessed problem sheets; project work assessment; performance in tutorials (usually not formally assessed).

Mathematical skills [2]

Definition: Understand and master the use of the most commonly used mathematical and numerical methods.

Teaching/learning

Example 1 (an individual strategy)

"*In lectures I first introduce the concepts and then I illustrate them making reference to examples from case studies from physics. Using a structured mathematical or analytical approach to problem solving help the students to understand the importance of mathematics.*

In problem classes the teachers give to the students regular question sheets at least one week in advance. Students are asked to find the answers during the week either by themselves or using textbooks or may be working in groups. Many of them do the job and during the class's one student at the time go to the blackboard to give his/her solution of the exercise and the others students make comments or criticize…

In computer classes, students use appropriate software such as programming languages and packages to solve numerical equations or non-analytical functions.

All of these approaches help the students to gain the mathematical literacy. "

Example 2

In order to improve the benefit of lectures, the teacher should "*give out all lecture notes to students so that they participate in lectures and do not have half of their minds closed, while concentrating on writing*."

Assessment

"*solutions to exercises are handed in at the scheduled time (shown on each sheet) for marking. The assignments form an essential part of the learning process and are used to give a mark, which is part (~1/3) of the formal assessment. The final writing exam is used to assess the achievement of the competence (~2/3 of the total mark)".*

An interesting form of assessment is in use at the other institution: "*each student will read and comment on another student's work (self selected pairs). They hand in the critique and their response to this as part of their self- assessment of the unit outcomes".*

Deep knowledge and theoretical understanding [3]

Definition: have a good understanding of the most important physical theories (logical and mathematical structure, experimental support, described physical phenomena), including a deep knowledge of the foundations of modern physics, say quantum theory, etc.

Teaching/learning

Example 1

"*for first cycle physics students this competence can only be acquired in a gradual way. Since they lack normally a profound mathematical knowledge at the start, the general physics courses can only be more descriptive in approach. When more mathematics is know, the intermediate and advanced undergraduate course units can present the logical structure of the discipline. Hereby the cognitive objective understanding or comprehension means the ability to identify; illustrate; represent; formulate; explain; contrast more and more the wide range of physical phenomena*". In this case one competence needs for its own development the development of another competence (i.e. Mathematical skills, see above). The lectures are of course the central elements in order to achieve this competence. Moreover the corresponding need of a harmonious curricular planning must be considered: *"In order to develop this competence particular attention should have been given to the physics course design. Indeed the student starts with a restricted knowledge of mathematics and is offered in the first bachelor year a more descriptive way of the physical phenomena. Because the student acquires in parallel a more elaborate mathematical knowledge, in the final bachelor he can be exposed to physics course units with a much deeper insight into the mathematical and theoretical structure of the discipline. Hence here we see how important it is that the different course units are particularly matched in this sense so that the degree of this ability can expand with the student progressing in the course".*

Example 2 (an interesting individual approach)

"*I help the students to achieve this competence by always giving them a very physical and broad (and even historical) introduction to the unsolved problems that gave origin to a new theory. In presenting the solution I then give different approaches like for example the operator and the path-integral approach. Furthermore I hint to less standard approaches and give them material and reading assignment if they want to study these topics further*".

Example 3

"*organizing discussion sessions in order to study or deepen some aspects of the physical theories, as explained during lectures".*

Example 4

Outline of a strategy aimed *to help students to overcome difficulties in understanding and in using the understanding:* (i) the recognition of the students starting level; (ii) a teaching progression appropriate to the potential of the students and related to the expected learning outcomes; (iii) the implementation of question sessions, in order to help students to formulate their own difficulties (which is the first step in order to overcome them); (iv) requiring self-study; (v) encouraging students in case of frustration.

Assessment

The assessment is quite traditional in this case (e.g. oral and/or written examination at the end of the unit or at the end of the whole degree-course). Moreover "*the student can still know if (s)he did achieve this competence in a sufficient way by listening carefully to the feedback (s)he receives from all the educational actors in the study programme. Normally they will tell the student that (s)he is lacking this competence, whenever the student progress in the course is unbalanced in favour of her/his pure empirical or experimental interest in physics. Nevertheless this competence could be felt as a sort of hidden variable, since its development should be built in a well-structured physics degree course".*

An interesting complementary way of assessment

oral comprehensive exams are used to assess quite effectively the degree to which students have overcome difficulties in understanding and in using the understanding. Those exams are taken by the end of the 4th semester in the subjects experimental physics, theoretical physics, mathematics and in an elective subject [and in the final oral MSc exam in experimental physics, theoretical physics and in two elective subjects].

Experimental skills [4]

Definition: be able to perform experiments independently, as well as to describe, analyze and critically evaluate experimental data and have become familiar with most important experimental methods

Teaching/learning

This competence is widely thought to be essential to any physics curriculum. The educational activities, which are appropriate for the development of this very competence are: lectures embedding practical demonstrations, lab classes, project work at Ba level (and Ma thesis in the second cycle). As to the amount of credits devoted to such activities, do recall the Tuning I results (cfr ref [7], page 200-201), where the total amount devoted to lab classes in the institutions of the Physics SAG is between 10 and 30 ECTS credits (with a slightly higher average amount in the second cycle), while the credits devoted to the final project may be as many as 25 ECTS (in the first cycle, where however for several institutions is simply "zero"!) and as 65 ECTS in the second cycle or in the integrated master level degree courses.

Assessment

The assessment of the achievement of this competence takes place through the students' written reports and oral presentations.

Problem Solving [5]

Definition: be able to perform calculations independently, even when a small PC or a large computer is needed, including capacity to utilize or develop computation systems or programmes for information processing, numerical calculus, simulation of physical processes, or control of experiments

Teaching/learning

The development / achievement of this competence is closely related to the development of the competence *Estimation skills* (see above), which is a kind of *simultaneously required* complementary competence. This latter is richly described above, also relying on some remarks given by the respondents within the context of the present *composite* competence, which might more appropriately be renamed as "**computer aided problem solving**".

This competence is perceived in at least two different ways:

a) *Using the computer in physics studies does not mean running an inherited code and getting output. It means doing physics with the help of computers. … Students do not usually employ existing software, but they have to develop their own.*
b) *The students are happy to learn one computing language (Fortran or C) and are very keen on using computer packages such as Mathematica and MatLab. The students also recognise a clear intention of most teachers in the department in developing this competence. They feel quite happy and confident at this level with their computer mastering. They seem a bit less confident about computer modelling*

At some institutions, in order to train students in this competence, all lectures are supplemented by exercise classes. More precisely, "*each of the four compulsory course units in theoretical physics, i.e., classical physics with mechanics, electrodynamics and relativity, quantum mechanics, statistical mechanics and advanced quantum mechanics with an introduction to quantum field theory, are supplemented by a computer project of ½ semester length ".* Moreover, the research training during the final master thesis work "*is usually also computer-based and therefore requires and trains computational skills in varying aspects depending on the research field, being it in theoretical, experimental or applied physics*".

At other institutions, computing and modelling skills are developed in specific computing classes (1st year) and then all across the curriculum. The used strategies are:

- *In lab reports all data should be treated using the appropriate computer tools.*
- *Individual (or group) home assignments are given in many disciplines that require the use of computer tools or modelling.*

In some specific units in the degree-course computer modelling and programming is set as one of the main learning outcomes (mathematical methods for physics, elasticity and fluid physics, computational physics).

Assessment

Also with regard to assessment there are complementary views:

a) *The development of the present competence is continuously assessed by the performance of students in the exercise classes accompanying the lectures, by grading the home work problems and the reports about the used methodology and the results obtained in the computer projects and – finally – by monitoring the progress of students during their research training. The basis for problem solving and for the effective use of computer skills is the understanding of physics. Thus, the continuous assessment of the student ability of problem solving yields very clear and effective indicators also for the general progression in understanding physics.*

b) *Most teachers give a strong weight to this competence in their evaluation (especially in those units / disciplines where it is stated as one of the intended learning outcomes).*

Physics culture [7]

Definition: be familiar with the most important areas of physics and with those approaches, which span many areas in physics.

Teaching/learning

The achievement of this competence is again a fruit of the whole degree-course. According to one of the respondents all teaching and learning of physics supports the development of a ***"physical world view",*** which is the ***"culture"*** of physics. Some anecdotes of history of physics and its heroes increase the feeling of togetherness and may also belong to the "culture".

Some activities however are proposed as examples of specifically targeted good practice, e.g. attendance at general interest lectures & seminars; students preparing short oral presentations on topics such as Nobel Prize winners or current technologies; moreover, informal groups of students aimed at solving exercise problems may help in developing a common "culture".

Assessment

There is no separate assessment for this competence, but the students' learning in this area will contribute to their overall performance in physics assessments. As case of interesting practice, at one Tuning institution the attendance to talks, seminars, etc. is assessed and form a small part of the laboratory mark.

6.3.3 – Physics Subject Related Competences – Second Cycle

Modelling skills [1]

Definition:

a) be able to identify the essentials of a process / situation and to set up a working model of the same;
b) be able to perform the required approximations; i.e. critical thinking to construct physical models;
c) be able to adapt available models to new experimental data.

Teaching/learning

The present competence focuses on the ability of critically adopting workable approximations for the solution of a given problem. We might more appropriately rename it as "**critical creative thinking**". Again we are facing a kind of composite competence, which clearly is developed throughout the curriculum.

A nice explanation / extension of the definition was given during our Tuning work:

Modelling in the general sense follows from understanding and requires applying that understanding. Modelling is therefore developed in all learning activities of physics.

Modelling in a narrow sense means finding a simplified mathematical description of a complex phenomenon. It is usually less than creating a proper theory. It often means also applying tools of theoretical physics to non-physics situations. Modelling is a phenomenological account of data in general, but it should also have some limited predictive power.

As to teaching/learning *there is no course unit named Modeling. Students learn the modelling description of nature throughout their whole degree-course*[15]. As a consequence the whole teaching offer becomes important: *in lectures, exercise classes, in lab classes, in student seminars and during research training students learn about how theories were developed, how to select and then apply theoretical tools* (including models) *to a particular physical problem and how to model the building blocks of a theory, by adapting these latter to the experimental data description.*

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[15] The respondent quotes as possible examples: the "modelling" neglect of friction in the description of the free fall, the abundant use of the harmonic oscillator for phenomena in the neighbourhood of stable equilibria, the shell model average field for nucleons in nuclei, the modelling of two-nucleon and three-nucleon forces, and so on.

On the other hand *students do not usually learn in compulsory or elective course units how to select and then to apply useful models taken from physics to non-physics phenomena*[16.] *Students* (usually or sometimes) *learn about this latter modelling as an exotic application of physics,* by attending seminars at the Department or elsewhere.

Assessment

The students` progress in developing this competence is assessed on the basis of their: (i) growing ability in solving exercise problems, (ii) written reports for the lab experiments, (iii) talks in student seminars, (iv) success in the comprehensive oral exams, (v) progress in research projects / Master thesis. Most of these activities are of course given marks, which contribute to the student's career.

Additional Teaching/learning strategies

Adding to all this, a couple of quite unforeseeable – at least at a first sight – teaching strategies may be envisaged for the development of this competence:

- a first strategy may be described as "promoting awareness of what is essential learning through general academic processes, which may help the so-called *critical thinking*". The involved processes are: (i) alumni take over part of a course unit, in order to give to the attending students an impression (or better an updated perception) of what professional employment/life is; (ii) students spend some time (e.g. during vacation) to learn about professional employment possibilities. (iii) students study abroad.
- a second strategy has to do again with being realistic, but on the side of the student, who should become able to adapt her/his own curriculum to individual wishes and potentialities. Indeed, *during year 4 and 5 of the physics curriculum (second cycle) course units and modules are offered, which allow for advanced and independent educational paths. Students have the possibility to arrange an individual programme by choosing lectures from a predefined list.*

In this more general context there are several educational activities, which develop the present competence: course-units, other lectures, seminars, laboratories, small group courses, poster presentations, discussions at oral presentations and discussions at conferences. Of course, a special attention should be paid to identifying examples of workable approximations, which are at the heart of this competence, and to becoming able to use them critically. The students should be able to compare the approximate solutions with existing *reference solutions* (e.g. exact and/or *ab initio* calculations or other more or less rigorous results) or even to produce new ones. This often implies that the students has to complete the offered educational activities with an effective use of the Department library and of the existing computer facilities, whenever this is appropriate and especially during project work and diploma thesis (when again the students perform *independent advanced studies* and may experience team-work).

Assessment

The assessment of this competence, which is very transversal to all educational activities, is intrinsically embedded in the traditional procedures, as in use for each specified educational activity (see list above), and it includes a range of options from giving marks to *individual / public* feedback.

Literature search [3]

Definition: be able to search for and use physical and other technical literature, as well as any other sources of information relevant to research work and technical project development. Good knowledge of technical English as well as on-line computer searching skills are required too.

Important premise

Nowadays part of this competence consists in knowing how to use the web resources: e.g. the intelligent use of search engines, such as Google, or the use of 'Internet Physicist', *a very handy free online tutorial designed to improve literacy and IT skills:* http://www.vts.rdn.ac.uk.

Of course, students who are not native English speakers need to be trained in the knowledge of (technical) English. A used strategy is addressing the students to evening classes or extra elective courses, where the necessary knowledge of standard and/or more scientific or technical English is offered.

Example 1

Teaching/learning

This competence may be developed the several ways through in traditional educational activities:

a. *Course-work and/or lab work: during lectures and in lecture notes: teachers should make full reference as most as possible to literature (also about historical experiments and older knowledge) in order to create interest and stimulate students to search by all means for original articles, already from the start of the studies; in laboratory classes: teachers should not always cite the needed data but stimulate the students to search them from all kinds of resources; in homework tasks and*

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[16] e.g., applying the dynamics of a linear chain or hydrodynamics to traffic problems, chaos theory to the stock market, diffusion equations to the territorial spread of species in nature or to the spread of opinions in society to the spread of national euro coins in euro-area and so on.

<u>problem sessions</u>: again teachers should not provide all needed data and should let the students search in books and/or databases, whose reference is given or whose reference has to be searched for.

b. *Project work: Students are most directly confronted with literature searching, when they have to add a reference list in presenting their project work; in this case they first have to go into detailed literature in order to present later on their work in an effective, authoritative and condensed way.*

The students are asked to develop this competence gradually. In the beginning of the degree-course they are stimulated to undertake the literature search themselves, but are not fully obliged; gradually in the lab sessions they receive more and more examples, up to the project work, where they cannot avoid it.

<u>Assessment</u>

The assessment is here almost only directly possible at the lab session or at the project work stage. This means that the supervisor checks during the academic year and at the end of the thesis work, to what degree the competence is achieved. The students then know if they have achieved this competence by all usul means of a regular feedback system. More particularly, in the project work, the supervisor regularly overlooks the progress in the project and – if needed – corrects the student for forgotten literature or stimulates the student in going to more details.

Example 2 (specifically targeted activities)

<u>Teaching/learning</u>

A seminar-based course, called 'Professional Skills for Physicists', is taken by all students in years 1 and 2. It includes exercises in finding sources and in summarizing information from them. This is supported by discussions with staff and with particular instruction in use of library and internet facilities. They also are required to give presentations in Year 1 on topics resulting from literature surveys. They also will do a project in Year 1, which will include a literature survey. The final research project, which starts in the 3rd year and lasts for one year will typically start with a guided literature search of a particular topic. The results of this must be reported by the student. Guidance on this is given in a special course called 'Research Interfaces'.

The students must fully engage in the above activities and present their results to the seminar leader, their tutor or their research supervisor. They are also required to prepare summaries of particular papers that they have identified and to give presentations on topics that they have researched in this way.

<u>Assessment</u>

Performance in written summaries and oral presentations in Years 1 and 2 are assessed and given a mark. Competence in this area as part of both the 1st year project and the final research project is assessed as a specific part of the students' project assessment. The summaries of papers are marked too.

Ability to Learn [4]

Definition: Be able to enter new fields through independent study.

<u>Teaching/learning</u>

The great European tradition is here well described by a sentence, which appears on the stained-glass windows of the Cathedral of Chartres, France: "*we sit on the shoulders of those giants who researched and learned before us and thus we are able to see farther*". In other words, starting from some background knowledge, one should be able to put new questions, to find answers, to re-organise her/his increased knowledge on the basis of the new findings. Apart from learning the basic physics theories (with the relevant mathematics), this competence is really thought to be most important.

In real practice, a much more pragmatic view is adopted. A Tuning SAG member states that this competence is acquired "by learning" and he identifies the open space, where to develop and practice such an ability, in that part of the curriculum, which the students plan on their own, by choosing units from a list or in a completely free manner. Indeed at the member's institution the compulsory units define only a small part of the programme (50 ECTS of physics units and 30 ECTS of mathematics units). The underlying philosophy is here that it does not matter so much what the students learn, but it matters that they learn (to learn).

Another SAG member, who did a small consultation among the students and the teachers at the home institution, found that both groups "*are unanimous in stating that the major strategy is to include in the teaching methods small individual and team project-works (either theoretical or experimental ones)".* Then the SAG member describes a case of good practice: "*since our degree-course is an applied one, most of the project works include an experiment: the students are asked to measure some quantity. Before doing the experiment itself, they have to plan it (experimentally and theoretically) and explain their choices (why are they using a given experimental method, which temperature intervals will they be covering, do they have everything in the lab or do they have to build some equipment or circuit in the workshop,…). The students then go to the lab and measure whatever is necessary. Afterwards they need to learn some new physics in order to interpret the data[17]. In the last two years some units give a weight as much as 50% and more to this type of work".*

[17] As a concrete example of project work (example given by a teacher): "*The student is given a thin quantum layer of material and is asked to identify the substrate and layer material and to measure layer thickness and the strain in the layer by optical spectroscopy. To accomplish this the student has to use several experimental techniques and to study new quantum physics*".

Familiarity with Basic & Applied Research [6]

Definition: acquire an understanding of the nature and ways of physics research and of how physics research is applicable to many fields other than physics, e.g. engineering; be able to design experimental and/or theoretical procedures for: (i) solving current problems in academic or industrial research; (ii) improving the existing results.

<u>Teaching/learning</u>

An important aspect of this competence, which was neglected in the definition, is "being familiar with problem decomposition". Here it would be again appropriate to remind the sentence in the Chartres Cathedral (see above, *Ability to learn* competence)

The Master thesis is here recognised as the key strategy for the development / achievement of this competence, but research activities as a part of the lab class, working groups and projects are considered important as well. During the Master thesis the students are often working in a research group, thus *taking part in "real" research*. In any case *the idea is to assign students a short research work that can be developed in a few months with the help of a tutor*. As to short projects, *they – although not really research projects – can also be assigned in advanced modules. These projects would require designing some experimental set-up or following some new theoretical procedure to solve a problem, i.e. they are projects which would require the development of something new from the point of view of the student, although it might not be really new for the Physics community*.

<u>Assessment</u>

The assessment of the Master thesis may become rather formal: *the research procedures and the results of the master thesis should have to be written and presented in front of a committee of professors, that will be able to evaluate and discuss with the student her / his results. It will be also important to evaluate the capacity of the students to relate their work with other work and results, which are already available in the literature*. On the other hand *the results of the small projects within a module can be written in a short note and evaluated by the professor in charge of the module, taking into account the student performance in the whole project.*

Familiarity with frontier research [8]

Definition: Have a good knowledge of the state of the art in - at least - one of the presently active physics specialities.

Example 1

<u>Teaching/learning</u>

The development of this competence is perceived by a SAG member as *an exciting way of learning, working or discovering*. … *The students are often surprised by the discovery of the organisation, which is implied by research.* He illustrates his experience as it follows: "*in advanced lectures such as Lasers Physics or Diluted Matter, in addition to the basic knowledge of the specific discipline, I teach the students how to approach the actual research area. When possible I illustrate the studied concepts by means of a current research problem. In problem classes the exercises are derived as far as possible from current research subjects. Finally all our second cycle students have to spend at least few weeks in a research laboratory. It is mostly at that time that they are confronted with a particular research subject. … It is surprising to see how much time and interest the students can spend on a particular research subject if they are interested. They read books chapters, magazines, they search on the web more information, they spend nights on computers…and discuss with researchers."*

<u>Assessment</u>

An interesting aspect is the assessment procedure of the advanced course unit: *"the basic knowledge is mandatory and it is assessed by a written exam, which is usually divided into three intertwined parts. The first part checks the understanding of (at least) part of the content, the second one is intended to control the mastering of mathematical and/or numerical methods and the third part deals with a recent theoretical or experimental result, for which the student is asked to answer an open question.*

Example 2

<u>Teaching/learning</u>

Different strategies consist of: attendance to invited research seminars (given by staff and visiting lecturers); attendance at national and international research conferences; asking the students to prepare posters and/or oral presentations on their research topics. These activities are usually not assessed.

Specific Communication Skills [11]

Definition be able to present one's own research or literature search results to professional as well as to lay audiences (orally and in written form to describe complex phenomena/problems in everyday language, as appropriate to the audience); be able to work in an interdisciplinary team

Teaching/learning

This definition is enriched by the students of a SAG member, who recommend to catch the listener's attention, e.g. by telling something, which is really new, and to avoid aseptic and cold wording.

The SAG members think that communication also includes "putting questions". Some of them desperately try during their lectures to encourage questions and moreover, when a question is put, they often ask the students to re-phrase it in a better manner, thus testing their capacity to communicate.

The following interesting example of good practice was quoted: "*I often take the students with me when I visit the high school they come from, in a campaign to attract students to physics. I then ask my students to talk to those pupils and say what it is like studying physics at our university ".*

A number of educational activities may contribute to develop the present competence. They are:

- *For lower level students: minor projects like the preparation of a poster, to be presented at the end of a course-unit in a special session. Such a task should teach the students how to make a long story short.*
- *During problem sessions students may be encouraged (or forced) to present their solutions on blackboard.*
- *Participation in and giving a talk in a seminar series is a compulsory part of the curriculum at the respondent's department.*
- *Preparation for and taking an oral examination (a respondent quotes as many as 27oral examinations at his institution in the first three years).*
- *oral presentation of extra topics, which the student may be reading for her/his thesis.*

Moreover at the department of one SAG member a specific course unit in scientific writing was recently started. In the Tuning SAG shares the view that a great challenge and opportunity to develop this skill lies in the final thesis work (either at Ba or at Ma level), which usually implies a written report. The role of the teacher here is to *point out to the student lapses of language and continuity; the possible lack of (clear) definitions and to suggest more adequate expressions for some concepts.* The final project often implies an oral presentation, with varying duration (up to half-an-hour for the Ba thesis and one-hour for the master thesis).

Assessment

As to assessment and feedback, the Master thesis is always given a mark, which includes as an important factor its readability/presentation. Similar assessment usually occurs for the Ba final project. The marks gained at the oral examinations include again a judgement about the present specific competence. As to the posters' good practice, which we mentioned above, it was reported that the students are encouraged rather than criticised during the poster session, but the posters are graded too, on a mild scale, yielding additional credit points for the degree-course.

Managing skills [12]

Definition: Be able to work with a high degree of autonomy, even accepting responsibilities in project planning and in the managing of structures.

Teaching/learning

This competence is very precious in the post-graduate life either in the job market or even in future research careers. It is well known, as an example in this latter respect, that many large experiments need strong leadership, endowed with extended managing skills. Moreover it becomes increasingly important to know the essential administrative elements, in order to achieve an effective funding of many research programmes and to optimise the use of different sources.

According to the SAG member from GR, at the level of a second cycle student life, this competence preliminarily implies a well-structured organisation of the student's own knowledge, starting from previous firm foundations. As a consequence an intelligent attendance to lectures is required, possibly free from constraints like "taking notes", which hinder a full openness of the mind to understanding. Lectures notes prepared by the teacher or annotated bibliographies, prepared by a group of students may quite help. Intelligent attendance also means some follow-up activities, like reading of recommended texts or preparing for the next lecture through some *discovery tasks*[18]**.** This competence further means: (i) Ability to analyse both oral and written texts to identify both surface and underlying meanings; (ii) Ability to describe and follow a well defined procedure to achieve a goal; (iii) Ability to manage the bureaucratic formalities a programme needs; (iv) Ability to have discussions (contacts) with other researchers in order to establish collaborations. The students develop these abilities mainly undertaking little research projects. A case of good practice is described in the following manner:

"*teams of students search, via internet, other research teams which deal with similar projects, and from their publications and sites draw useful information concerning their work (methods, installation, staff, etc). The students' team then has to:*

- *classify similarities and differences of its own project work with respect to the project of other research teams;*
- *classify similarities and differences in order of importance;*
- *make a list of lacking equipments;*
- *get in touch with companies and their product catalogues;*
- *estimate costs and – in case – search for alternative choices.*
- *make presentations of its work e.g. in posters;*
- *see and understand other students' similar work*."

[18] e.g. thinking about and possibly solving a problem, assigned by the teacher and allowing to enter the contents/issues of the forthcoming lecture.

Assessment
In this case the assessment occurs mainly through the unit feedback session, when students are asked to consider their own performance and contribution. In particular there is a question about what anyone personally considers as being the key step for the success of the whole process. The student feedback is summarised anonymously and then discussed as a whole group, so that issues about achievement can be discussed as well, including the annotated comments pointing out where the students could have gone further in developing knowledge and concepts.

6.3.4 – Conclusions
According to the Tuning Physics community, the 13 competences described above are the most important subject related competences to be developed in a Physics degree-course. Their descriptions mainly rely on the answers to the Athens homework. Taking into account the fact that each competence was described by at most two respondents, it may very well be that some important aspects have been lost in each single description. However each description gives in itself extended material for reflection. Sometimes, even recognising that only *normal* everyday-life behaviour occurs may be encouraging in itself. Moreover precious (sometimes really original) ideas pop up here and there in the above review. The cases of good practice seem limited in number, but it is difficult to identify them on the basis of common and shared criteria. Some descriptions among the ones given here, apparently without any innovative character, may nevertheless be considered as cases where *things are really well done!*. Our hope is that these descriptions may raise awareness about the importance of subject related competences in curricular design and stimulate actions aimed at improving the way the several educational activities are offered to students and the transparency in assessment procedures. Our further hope is that each institution by comparing its teaching/learning approach with the meaningful variables, as outlined in §6.2 above, and with the many existing patterns of behaviour, may improve its general approach to teaching / learning, without loosing the values of its traditional identity.

As to the assessment procedures, on the basis of the review in this Section, it clearly appears that the achievement of most of the Tuning competences cannot be “measured” as such, but it contributes to the marks of the educational activity under assessment in a varying and usually complicated manner. An alternative monitoring tool consists in the feedback procedures, which are envisaged case by case and which contribute to enhance the quality of the student’s preparation, but which do not usually lead to formal assessment.

7. REFERENCES FOR FURTHER INFORMATION (concerning Physics)

In recent years many papers and materials were produced both by the Socrates Thematic Network named EUPEN – European Physics Education Network (and now named STEPS by EUPEN) and by the Tuning Subject Area Group. We list here the papers *quoted in / relevant for* the present brochure.

[1] LF Donà dalle Rose, W.G. Jones, S. Steenstrup, L. Tugulea, FJ van Steenwijk Report of Working Group 1: *The student experience (The questionnaire on the doctoral studies),* pages 13 - 46 in "Inquiries into European Higher Education in Physics", Proceedings of the third EUPEN General Forum 99, London (UK), September 1999, edited by H. Ferdinande & A. Petit , Volume 3, Universiteit Gent, Gent 1999

[2] E. Cunningham, A. Konsta, C. Ferreira, D. Chasseau, I. Sosnowska Report of Working Group 3: *Organisation of Physics studies (The questionnaire on the doctoral studies),* pages 73 - 94 in "Inquiries into European Higher Education in Physics", Proceedings of the third EUPEN General Forum 99, London (UK), September 1999, edited by H. Ferdinande & A. Petit , Volume 3, Universiteit Gent, Gent 1999

[3] LF Donà dalle Rose, W.G. Jones, S. Steenstrup, L. Tugulea, FJ van Steenwijk *Dissemination Report of Working Group 1: The student experience in "Inquiries into European Higher Education in Physics*", Summarising report of EUPEN Activities and Results in Socrares phase I & Proceedings of the three EUPEN regional fora – 2000, edited by H. Ferdinande & E. Valcke, Volume 4, Universiteit Gent, Gent 2000. The figures shown here are part of a presentation given by FJ van Steenwijk in the EUPEN regional forum held in Barcelona, September 2000.

[4] LF Donà dalle Rose, W.G. Jones, S. Steenstrup, L. Tugulea, FJ van Steenwijk *Report of Working Group 1: The student experience (The questionnaire on the teaching learning styles and the questionnaire on the "private study part" of the student experience)* in "Inquiries into European Higher Education in Physics", Proceedings of the second EUPEN General Forum 98, Dublin (IE), August 1998, edited by H. Ferdinande & A. Petit , Volume 2, Universiteit Gent, Gent 1999, pagg. 21-72

[5] S. Steenstrup, LF Donà dalle Rose, W.G. Jones, L. Tugulea, FJ van Steenwijk, *Physics studies in Europe; a comparative study*, Eur. J. Phys. **23** (September 2002) 475-482.

[6] F Cornet, LF Donà dalle Rose, E Cunningham, MC do Carmo, M Ebel, H Ferdinande, H Geurts, E Gozzi, WG Jones, J Niskanen, G Nyman, JC Rivoal, P Sauer, S Steenstrup, EG Vitoratos: *TUNING PHYSICS NETWORK – Line 1, Learning Outcomes: Generic Skills*, Proceedings of the Sixth EUPEN General Forum EGF-2002, " Convergence of Physics studies in Europe?", Varna, September 6th-7th, 2002, ed. by H Ferdinande, T. Formesyn & E. Valke, Volume 7, EUPEN Consortium, Univ. Gent, 2003.

[7] LF Donà dalle Rose, F Cornet, E Cunningham, MC do Carmo, M Ebel, H Ferdinande, H Geurts, E Gozzi, WG Jones, J Niskanen, G Nyman, JC Rivoal, P Sauer, S Steenstrup, EG Vitoratos: *PHYSICS SUBJECT AREA GROUP: Part 2. OPERATIONAL DEFINITIONS OF THE CORE CONTENTS*, pages 185 – 211 in "**Tuning Educational Structures in Europe, Final Report, Pilot Project – Phase 1**, *carried out by over 100 Universities, coordinated by the University of Deusto (Spain) and the University of Groningen (The Netherlands) and supported by the European Commission*", eds Julia Gonzalez and Robert Wagenaar, University of Deusto and University of Groningen, 2003.

[8] LF Donà dalle Rose, F Cornet, E Cunningham, MC do Carmo, M Ebel, H Ferdinande, H Geurts, E Gozzi, WG Jones, J Niskanen, G Nyman, JC Rivoal, P Sauer, S Steenstrup, EG Vitoratos: *PHYSICS SUBJECT AREA GROUP: Part 1. THE ACADEMICS' EVALUATION OF THE SPECIFIC COMPETENCES*, pages 171 – 185 in "**Tuning Educational Structures in Europe, Final Report, Pilot Project – Phase 1**, *carried out by over 100 Universities, coordinated by the University of Deusto (Spain) and the University of Groningen (The Netherlands) and supported by the European Commission*", eds Julia Gonzalez and Robert Wagenaar, University of Deusto and University of Groningen, 2003.

[9] "*University Autonomy in the European Context: Revisiting the Research – Teaching Nexus in a Post-Humboldtian Environment*", Background document commissioned by the Magna Charta Observatory, on the occasion of its Yearly Conference in Bologna, September 2005, to Univ. Prof. Dr. Ulrike Felt and prepared in collaboration with Mag. Michaela Glanz, Department of Social Studies of Science, University of Vienna, 2005.

[10] see Section 3.3 and Appendix 8 in "*A Framework for Qualifications of The European Higher Education Area*", Bologna Working Group on Qualifications Framework, published Ministry of Science, Technology and Innovation, Bredgade 43, DK-1260 Copenhagen K, February 2005.

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