European Benchmarks for Physics Teaching Degrees

1. Summary

This is a proposal to produce a common European Benchmark framework for degrees in physics teaching. Since school systems throughout Europe vary widely, it did not seem practicable to provide benchmarks for teachers for all different age groups and for schools with different academic or vocational profiles. Therefore we concentrate on degrees for physics teachers in upper secondary school (ages 14-18) and, in case there are secondary schools of various types, on schools that qualify their graduates for academic studies.

In order to inspire their pupils and respond to their questions, such teachers in particular should be able to keep up with the latest developments in physics and its applications. They should therefore have completed an academic course of studies, preferably at master level. Such a course will contain physics, physics teaching and learning (didactics of physics), applied pedagogy, as well as supervised practice periods in schools. In countries where teachers are required or expected to qualify in more than one subject, a second subject of equal weight and its didactics will also be included[1]. These components may be distributed in various ways over the bachelor and master stages, so we decided to just list the essential competences that should have been acquired at the end of the course of studies, when graduates can enter the school system as salaried teachers, possibly in a provisional capacity. In particular some of the more practical skills will need some further honing, during the first years of professional experience.

This proposal is intended as an indicative listing, which broadly specifies the qualifications included in most physics teaching degrees across Europe. In addition we specify a core curriculum for the fields of physics and didactics of physics, which also reflects the standard throughout most of Europe. We hope they will provide a frame of reference for departments planning or adapting such courses of studies, and for comparison of such courses. However, since they cover only curriculum and competences, they are not intended to either provide a fixed and detailed syllabus or to replace quality control guidelines in force in various countries, which in general have a broader scope and take national specifics into account.

Since in many European countries there is a severe shortage of qualified teachers, it may be unavoidable that some physics lessons are taught by teachers that do not satisfy all the requirements specified here, or by physicists or other professionals without full pedagogical and didactical training. For such teachers, programmes of in-service training should be offered that allow them to supplement their education and attain the level of qualification specified here.

2. Introduction

The last decade has seen rapid developments of university physics programmes. A principal driving force has been the transition to the Bologna architecture, which should provide a common structure for university degrees. Meanwhile, bachelor programmes have been established in virtually all European countries, and the introduction of master programmes is at least in its first stages. The transition has led many departments to rethink and redesign their programmes, often beyond the strict Bologna requirements. A second agent of change has been the introduction of various systems of quality control, in particular accreditation. Such systems have been established mainly on a national basis, but they are increasingly acquiring an international dimension. In the accreditation process, learning outcomes have to be specified, and a programme must in general be shown to fulfil international standards.

University educators, both in physics and in other subjects, have felt the need to exchange experiences and ideas with colleagues in other European countries in the context of European networks, generally supported by the European Commission. The physics education network EUPEN, continued in the STEPS and STEPS TWO projects[2], has been one of the earliest and most successful ones. Physicists also participated prominently in the interdisciplinary TUNING[3] projects. More recently, the European Physical Society, whose members are National Physical Societies, carried out a study on the Implementation of the Bologna Process in Physics. In the context of this study, specifications for physics Bachelor, Master and doctoral studies were formulated[4]. The Bachelor document contains much more detailed curricular benchmarks, (Eurobenchmarks) produced by the STEPS TWO network.

Within the STEPS TWO network it was decided to attempt formulating a similar document for physics teaching degrees. In view of the large variety in school systems, and in teacher education systems as well, it was decided not to try to produce separate documents for Bachelor and Master Degrees, but to concentrate on the qualifications a teacher should have when he or she enters the profession, possibly on a provisional basis. Also, though in many regards the standards are valid for teachers for other age groups, the emphasis will be on teachers in upper secondary schools. Where there are different types of secondary schools, the emphasis will be on the types that prepare pupils for university studies. The Eurobenchmarks document for the Physics Bachelor programme concerned itself mainly with curricular standards, since specifications of competences had been formulated in other documents, e.g., from the TUNING project, and were concurrently being addressed in the EPS Bologna project. In contrast, we decided to also include competences (learning outcomes) in the present document. Many universities have formulated qualifications to be acquired by physics teacher education programmes (e.g., the Johannes Kepler University in Linz and the Free University in Amsterdam). Qualifications for science teachers were formulated in the European Pathway project[5]. The German and US task forces referred to below also considered physics teacher qualifications. These documents show broad agreement, but they differ in scope and level of detail, so we deemed it useful to include a specification broadly reflecting this European consensus roughly on the level of detail found in ref 4).

In physics teacher education programmes, there has been an additional reason for redesigning curricula. In many European countries, the number of students choosing physics or other science and engineering subjects has been declining, or at least stagnating. This threatens not only the future of these academic disciplines, but also the ability of European economies to stay in the forefront of technological innovation, as well as the prospects for informed discourse in society on questions related to science and technology. It was soon realised that the quality of high school teaching is a crucial factor in recruiting students to physics in particular and to science and engineering in general. At the same time, PISA[6], TIMSS[7] and similar studies showed that the stated aims of science teaching in high schools were often reached at best incompletely.

As part of the solution, a restructuring of the education of physics teachers was envisaged in many European countries, e.g., the recommendations[8] of a working group of the German

Physical Society (DPG). An important element was the increase in the role of physics-related pedagogy (didactics of physics). Education in didactics should be research based, just like the physics parts of the curriculum, and research in physics education should be promoted as well. In the US, where similar or even more severe problems exist, a Task Force on Teacher Education in Physics[9] was set up by the American Physical Society, the American Institute of Physics and the American Association of Physics Teachers. It recently presented its findings and recommendations.

In the next section, we formulate the competences a teacher should have in the fields of Physics, Physics Teaching and Applied Pedagogy, as well as some social competences essential to functioning as a teacher. The latter two are not specific to physics, but they are included both for completeness and because they may play a role in the design of the programme in Physics Teaching and even the Physics part (e.g., concerning communication skills). The following two sections contain the core curriculum, first in its general structure and then in more detail. The final section contains a few remarks on possible uses of these benchmarks.

3. Competences

A physics teacher should have acquired competences in Physics, Physics Teaching (Didactics of Physics) and Applied Pedagogy as the result of an education that is research based in all three components. He or she should keep these competences up to date by following new developments in these areas by means of in-service training and individual study, and have acquired the studying skills to do so effectively. A teacher also needs social competences to function effectively. He or she should be willing and able to convey the importance and relevance of physics and the technologies based on it, both in the school and in society at large, and thereby promote and contribute to a broad and informed discussion about scientific and technological developments throughout society.

Physics competences

A teacher should have a broad knowledge and understanding of Physics, especially of those parts that form the background for the physics taught in school. This implies in particular:

- Familiarity with the most important areas of physics. the concepts used, the style of reasoning and the methods used to solve problems;
- Understanding the most important physical theories, their logical and mathematical structure and their relation to observation and experiment;
- Familiarity with the principal experimental techniques; the ability to carry out simple experiments independently and to handle and interpret the data obtained from them:
- The ability to use the physics literature and other sources of information for answering and solving specific questions and problems, e.g., as arising from new developments in physics and its applications reported on in the media;
- Appreciating the methods and procedures used in physics research, including the ability to illustrate them by specific examples; some research experience (not necessarily in physics for two-subject teachers);
- A basic knowledge of the historical development of physics and of its importance for technology and for other sciences.

Physics Teaching competences

A teacher should be skilled and confident in mediating physics content. This implies in particular:

- The ability to introduce pupils to the nature and values of science, the scientific way of thinking and reasoning, also in contrast to other ways of knowing, as well as to the language used in science and physics; the ability to promote science literacy and a disposition towards inquiry and active learning;
- The ability to explain even complex physical problems using language and mathematical tools adequate for pupils in secondary schools, making use of different representations (e.g., verbal, visual, graphical and mathematical) and relating them wherever possible to their everyday experiences;
- The ability to respond adequately to pupils' questions on physics and to give them constructive feedback on their work and progress;
- The ability to design a coherent lesson plan taking into account the curricular standards, the legal and regulatory framework, and the specific problems of teaching physics in secondary schools;
- The ability to execute this plan in everyday school practice, to choose and design adequate teaching materials, to reflect on the experiences made and to make use of them to improve one's teaching;
- Knowledge of and experience with a broad spectrum of teaching methods, in particular with planning and execution of demonstration experiments, student laboratories and project assignments; the effective use of computers and multimedia for teaching and learning; designing a mix of such methods for optimal motivation and understanding: knowledge of and experience with various assessment and testing methods:
- The ability to understand the typical style of reasoning of pupils and their prior conceptions about the physical world, to identify misconceptions and conceptual difficulties and to develop strategies to overcome them. This includes the recognition of gender- and class-specific factors in motivating pupils and in conveying physics contents to them.

Applied Pedagogy competences

This means the willingness and ability to contribute to the development of children, young people and adults by education and teaching. This implies in particular:

- Knowledge of basic pedagogical and psychological concepts on teaching, learning, education and development and the ability to analyse, understand and influence practical pedagogical processes using contemporary assessment strategies to evaluate intellectual, social and personal development of the learner;
- Familiarity with instruments and methods of teaching and the ability to apply them to design and shape teaching situations, to diagnose learning difficulties and to estimate and test progress in the attainment of pedagogical aims:
- The ability to reflect on one's functioning as a teacher and educator, to learn from experience to further develop one's competences as a teacher.

Social competences

- The ability to communicate effectively with pupils and groups of pupils;
  Recognizing and handling learning and development problems ;
  The ability to handle conflicts;
  Creating an atmosphere in class that furthers motivation and successful learning and the integration of all pupils into the class community (classroom management);
- The ability to communicate effectively with parents, parent representatives and other stakeholders;
- Willingness and ability to function in a team, both with fellow physics teachers and with teachers of other subjects, in order to coordinate and develop teaching and education and to further the successful functioning of the school.

4. Overall curricular structure

To function effectively, a teacher needs academic competence, obtained by a research based education, preferably at master level. The following survey does not include the full course of studies, but only the part concerning Physics and the Teaching of Physics. Excluded are Applied Pedagogy and practice in schools, as well as the second subject, where required. Bachelor and/or Master Theses are also not included. To obtain a basic research competence, future teachers should write such a thesis, but not necessarily in Physics or Didactics of Physics in two-subject programmes.
On the basis of the EUPEN and TUNING studies, seven broad areas of study or streams have been identified. Six of these are essential for a physics teaching degree and clearly compulsory; the seventh is provided for optional specialisations; it can also be a subject (or subjects) related to physics. Examples are Chemistry, Astronomy & Astrophysics, History and Philosophy of Science, Geophysics and Meteorology, Biological or Medical Physics, or Electronics. This seventh stream may also be omitted.

The streams are indicated in the following table. Overall, in two-subject programmes there would have to be at least 90 ECTS credits in Physics (including auxiliary mathematics) and Didactics of Physics, divided over the streams within the ranges indicated. In one-subject programmes one will need to move closer to the maximum of the ranges specified to reach the required scientific competence. Typically, these ranges are 10-20 credits, with the exception of the stream didactics of physics, which has 15-30, and the optional subject(s), which has 0-30. Most modules or course units should be attributable to one of the streams, based on their contents, even if they contain some subjects from other streams. Occasionally, however, they may need to be split between areas. The listing is not intended to indicate a temporal order of the subjects or a grouping into modules or other units.

Physics and Physics Teaching Core Curriculum

- **Mechanics & Thermodynamics** (10-20 credits)
  Classical Mechanics, Thermodynamics & Kinetic Theory, Special Relativity
- **Optics and Electromagnetism** (10-20 credits)
  Oscillations and Waves, Basic Optics, Electromagnetism, Electrodynamics and Wave Optics
- **Quantum Physics and Structure of Matter** (10-20 credits)
  Quantum Mechanics, Statistical Mechanics, Solid State Physics, Atomic, Nuclear and Particle Physics
- **Experimental/ Laboratory work** (10-25 credits)
- **Mathematics & IT** (10-20 credits)
  Mathematics, IT and modelling
- **Didactics of Physics** (15-30 credits)
- **Physics-related Optional Subjects** (0-30 credits)
  A subject or subjects related to physics, a subfield of physics or applications of physics not contained in the earlier streams

Note: ECTS credits total 60 per year.

A more detailed structure for the benchmarks is given in the following section. In order to keep this table to reasonable size the topics have been given as headings which should be understandable to physicists. We did not specify learning outcomes for each of the subjects, since generic learning outcomes were specified in the preceding section.

Though the subject catalogue (but for stream six) has a large overlap with that for the physics Bachelor programme, the emphasis in a teacher training programme will often be different, with less attention given to advanced computational skills and specialized topics, and more to basic conceptual issues and to applications to daily life. Though we distinguish Physics and Teaching of Physics in the listings above and below, there may be courses containing aspects of both, especially in laboratory work or concerning physics in daily life.

5. Detailed curricular structure

The following table relies heavily on the IOP document[10] for the Bachelor core curriculum, from which most subject descriptions have been taken or adapted. The table contains only core contents, and the items cannot all be treated in the depth and to the level of detail usual for a physics degree, especially in a two-subject curriculum.

Mechanics and Thermodynamics
(10-20 credits)

Classical Mechanics:
Newton's laws and conservation laws, including rotation;
Newtonian gravitation to the level of Kepler's laws.

Thermodynamics and kinetic gas theory:
Zeroth, first and second law of thermodynamics, to include:
Temperature scales, work, internal energy and heat capacity:
Entropy, free energies and the Carnot cycle;
Kinetic theory and the gas laws; states of matter and changes of state;
The Maxwell-Boltzmann distribution:
The statistical basis of entropy.

Special relativity:
to the level of Lorentz transformations and the energy-momentum relationship.

Optics and Electromagnetism
(10-20 credits)

Oscillations and waves:
Free, damped and forced oscillations, to include resonance and normal modes;
Waves in linear media;
Waves on strings, sound waves and electromagnetic waves;
Doppler Effect.

Basic Optics:
Geometrical optics to the level of simple optical systems;
The electromagnetic spectrum;
Polarization of light;
Interference and diffraction at simple and multiple apertures;
Dispersion by prisms and diffraction gratings;
Optical cavities and the basic principle of laser action.

Electromagnetism:
Electrostatics and magnetostatics;
DC and AC circuit analysis to the level of complex impedance;
Gauss, Faraday, Ampère, Lenz and Lorentz laws to the level of their vector expression.

Advanced electrodynamics and optics:
Maxwell equations and their plane wave solutions;
Waves at planar interfaces.

Quantum Physics and Structure of Matter (10-20 credits)

Historical background and fundamental phenomena:
Black body radiation; the photoelectric effect;
Wave-particle duality;
Heisenberg's uncertainty principle.

Quantum mechanics:
Schrödinger's wave equation to include:
The wave function and its interpretation;
Standard solutions of simple systems, to include the hydrogen atom:
Tunnelling.

Statistical mechanics:
Microscopic foundation of thermodynamics;
The density of states and the partition function;
Bose-Einstein and Fermi-Dirac statistics.

Atomic, nuclear and particle physics:
Quantum structure and spectra of simple atoms;
Nuclear masses and binding energies:
Radioactive decay, fission and fusion;
Elementary particles and fundamental forces.

Solid state physics:
Mechanical properties of matter to include elasticity and thermal expansion;
Inter-atomic forces and chemical bonding;
Phonons and heat capacity;
Crystal structure and Bragg scattering;
Semiconductors and doping:
Magnetic properties of matter.

Experimental and Laboratory work
(10-25 credits)

Planning an experimental investigation;
Using apparatus to acquire data;
Analysing data using appropriate techniques;
Determining uncertainties (both systematic and random) in an experiment or observation;
Reporting the results of an investigation;
Understanding how regulatory issues such as health and safety influence scientific investigation and observation.

Mathematics and IT
(10-20 credits)

Mathematics:
Complex numbers;
trigonometric and hyperbolic functions;
Series expansions, limits and convergence;
Calculus to the level of multiple integrals;
Solution of simple linear and partial differential equations;
Vectors to the level of grad, div and curl; Gauss' and Stokes' theorem;
Matrices to the level of eigenvalues and eigenvectora;
Fourier series and transforms;
Probability distributions.

Modelling and IT:
Data calculation, processing and presentation;
Information searching;
Modelling of physical systems.

Physics Teaching (Didactics of Physics)
(15-30 credits)

School physics:
Structure of the curriculum; national standards (if any) for curriculum and final examination:
Adapting the presentation to the pupils' mathematical level; using multiple representations.

Pupils' reasoning style and misconceptions:
Recognizing the typical style of reasoning of pupils, appreciating their prior conceptions of the physical world, identifying and overcoming their conceptual difficulties and misconceptions.

Teaching methods:
Different methods of teaching, their advantages and disadvantages; evaluation of teaching results; design of problem solving activities; tests and examinations.

Experiments in school:
Design and execution of demonstration experiments, including their effective didactical use; Design of hands-on experiments for pupils, including their effective didactical use; Equipment and maintenance of a school laboratory

Computers and multimedia:
Effective use of educational software, including simulations and visualisation;
Digital information searching.

Physics in other sciences and in everyday life[11]:
Relating physical concepts to everyday experiences;
Physical principles of common equipment and machinery;
Physics in medicine and sports;
Physics of climate, energy use and the environment.

Practice periods
Preparation for and reflection on practice periods in schools (aspects specific to physics)

Physics-related optional subject(s)
(0-30 credits)

A subject or subjects related to physics, or a more extended treatment of a subfield of physics or fields of application of physics not contained in the listings above (this stream may also be omitted). Examples are: Chemistry, Astronomy and Astrophysics, History and Philosophy of Science, Geophysics and Meteorology, Biological or Medical Physics or Electronics.

6. Possible uses of this document

We hope this document can be of use to departments designing or adapting their physics teacher education programmes, both regular ones and special ones to qualify teachers in other fields or physicists or engineers without teaching education to become physics teachers. It could also be used as a reference frame in the context of programme evaluations and quality control procedures.

In countries where, in response to a severe shortage of qualified teachers, lessons are taught by teachers with a lesser qualification, or by physicists or other professionals without education in didactics on an emergency basis, it could serve as a guideline to design in-service education programmes to enable such teachers to improve and supplement their qualifications.

Finally, it might play a role in furthering comparability of degrees and thereby the mobility of teachers. Though the mobility of teachers lags far behind that of researchers, due mainly to language difficulties and differences in school systems, it is expected to increase, and conformity to the standards formulated here could play a role in the recognition of qualifications acquired in another European country.

Appendix:

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[1] Less commonly, there may be several additional subjects, in general not all qualifying to teach the highest age group.

[2] http://www.stepstwo.eu

[3] http://www.tuning.unideusto.org

[4] http://www.eps.org/activities/education/eps-physics-education-studies

[5] http://www.bayceer.uni-bayreuth.de/pathway/

[6] http://www.pisa.oecd.org/pages/0,2987,en_32252351_32235731_1_1_1_1_1,00.html

[7] http://www.timss.org/

[8] http://www.dpg-physik.de/static/info/lehramtsstudie_2006.pdf (German)
http://www.dpg-physik.de/veroeffentlichung/broschueren/studien/lehramt-eng_2010.pdf (English)

[9] http://www.ptec.org/webdocs/TaskForce.cfm

[10] http://www.iop.org/activity/policy/Degree_Accreditation/file_26578.pdf

[11] The underlying physics is in general taught in the physics curriculum; in didactics of physics, it is shown how everyday life examples can be used to make pupils appreciate the scope and various uses and applications of physics)