Subject-Specific Criteria of the Technical Committee 05 – Physical Technologies, Materials and Processes

for the accreditation of Bachelor and Master Degree programmes in Physical Technology, Material Science and Material Engineering.

(adopted: 29 September 2016)

The following specifications complement the “ASIIN General Criteria for the Accreditation of Degree Programmes”.

1 Preliminary Note

1.1 Context and Function

1.1.1 Context

The Subject-Specific Criteria (henceforth the SSC) of the Technical Committee 05 – Physical Technologies, Material Science, Material Engineering and Processes (henceforth TC 05) were developed in cooperation and coordination with the relevant professional communities and faculty and subject area day meetings. Thus, the SSC align with current internationally accepted standards and contribute to the realisation of a unified European higher education area. The SSC address the demand to formulate subject-specific and discipline-oriented learning outcomes as one of the most important quality criteria towards promoting academic and professional mobility in Europe. The SSC take into account the diverse preparatory work that has been done within the framework of European projects and professional networks.

1.1.2 Function

The SSC of TC 05 are intended to support higher education institutions in formulating their self-evaluation reports for the purpose of accreditation processes. Applicant institutions are responsible for defining the intended learning outcomes and their degree programme profiles. This definition will then provide the main standard for the curricular evaluation by ASIIN. Under no circumstances should institutions be restricted in the development and testing of newly reformed degree programmes or degree programmes requiring a specific profile. Within the de-
gree programme objectives and profiles as defined by the institutions, deviations from the in the SSC defined abilities, skills and competencies are allowed.

The SSC are generally the result of regularly planned assessments by the ASIIN Technical Committees. The SSC summarise what is considered good practice between academics and practitioners of the professional community, or, what is required as future-oriented educational quality by the labour market. The expectations outlined in the SSC for the achievement of study objectives, learning outcomes and competency profiles are therefore not to be evaluated in a static manner. Rather, they are subject to constant review and further development in close cooperation with organisations of the „professional community“, such as faculty and subject area meetings, expert associations and federations of professional practice. With the help of the SSC, applicant institutions are requested to critically reflect on the interaction between their own formulated intended learning outcomes, the curricula, teaching and learning methods and the associated quality expectations, so as to position and profile themselves in light of their own institutional objectives.

The SSC should be viewed as a basis for professional discussions between experts, higher education institutions and the ASIIN committees. They include the most important abilities, skills and competencies that are typically considered current „state of the art“ within the subject area. They are meant to contribute significantly to the comparability of national and international accreditation procedures. The choice of professional parameters that influence the discussion and individual evaluation should not be subject to random professional interpretation of the individual experts. The study objectives and competency profiles as described in the following paragraphs for Bachelor and Master Degree programmes in Physical Technologies, Material Science and Technology, are thus meant as a practical guide for the application and evaluation of accreditation procedures.

1.2 Responsibilities and Definitions

The TC 05 is responsible for the evaluation of Bachelor and Master Degree programmes in Material Science and Technology, Physical Technologies and strongly interdisciplinary oriented programmes within this field. Degree programmes with a heavy content in Physical Technologies, Material Science and Technology as well as process related content are typically led by TC 05. In interdisciplinary degree programmes where the content in Physical Technology, Material Science or Technology is rather marginal, TC 05 is jointly responsible together with the participating disciplines or will only provide auditors.

Physical Technologies

The thematic group „Physical Technologies“ contains Bachelor and Master Degree programmes that combine an extensive mathematical and physical foundation and principles with other appropriate engineering or natural scientific focus areas (e.g. Mechanical Engineering, Microsystem Technology, Electrical Engineering, Computer Engineering, Optical Technologies, Medical Technology, etc.) within a complete degree programme. Within this term, degree programmes that present an extensive cross-sectional nature, which makes it impossible to classify these under only one discipline, are also included. Generally, this makes the mathematical and natural science portion of the study programme larger than it is for instance in more classic degree programmes like Electrical Engineering and Mechanical Engineering. The relevance and value of degree programmes in Physical Technology lies within their special role as a bridge between physical research, technological development and industrial application.
Examples of focal points within the area or with the contribution of Physical Technologies are **Optical Technologies, Micro-system Technology, Nano Technology, Surface Technology, Medical Technology, Bio Technology or Measurement Engineering/Sensor Technology**.

**Material Science and Engineering**

Bachelor and Master Degree Programmes that focus on Material Sciences and Material Technologies/Engineering are classified under the thematic group „Material Science and Engineering“*. They cover a wide range of natural-scientific fundamentals of material properties, from production and processing up to application and failure of materials. They also combine the fundamental principles of experimental and theoretical material sciences with physical-chemical fundamentals as well as with engineering focal points.

Typical focal points in the area of or with the participation of Material Science are, among others, **functional materials such as magnetic, optic or semiconducting materials, nano materials, hybrid and composite materials, thin coatings, powdered or sintered materials, polymers, plastics engineering, physical metallurgy, analytical chemistry of materials, materials technology and processing, failure diagnostics, biomaterials**.

### 1.3 Collaboration of the Technical Committees

The TC 05 collaborates closely with ASIIN’s other Technical Committees to meet the requirements of interdisciplinary degree programmes. Following an application for an accreditation procedure, institutions are invited to submit their own assessment of which Technical Committee(s) their degree programmes should be assigned to.

### 2 Educational objectives and learning outcomes

The educational objectives that graduates need in the professional field or in further studies, i.e. knowledge, abilities and competencies, are clarified in a short and concise description. These educational objectives are developed according to various objectives of Bachelor and Master Degree programmes regarding scope and depth.

#### 2.1 Requirements for Bachelor Degree programmes

A Bachelor degree is aimed to facilitate an early entry into a professional career in the area of Physical Technologies or Material Science and Material Engineering (professional qualification) on the one hand, and on the other it should qualify graduates for advanced scientific degree programmes or an additional scientific degree programme in a different area of study.

Completion of a Bachelor Degree programme should lead to the following objectives or learning outcomes:

**Knowledge and Comprehension**

Being in command of the fundamental knowledge and comprehension of Natural Sciences, Mathematics and Engineering forms the basic competencies to achieve further educational objectives.
Graduates:

- Know and comprehend the principles of Natural Sciences, Engineering, Technology and Mathematics that are the basis of the subject area of their focal studies,
- Have a systematic comprehension of the central elements and concepts of the subject area of their focal studies,
- Possess interdisciplinary (coherent) knowledge on the subject areas of their focal studies
- Have knowledge of additional aspects of subject related sciences.

**Analysis and Methodology**

The ability to analyse systemically can encompass identification of a problem, clarification of a specification, reviewing possible solutions, selection of the most suitable method and its implementation. In order to perform these different analytical processes with high quality and achieve good and sustainable learning outcomes, knowledge and command of proven scientifically based methods is necessary. The fundamental principles of relevant methods must be known and understood. They must be mastered by the graduates.

The graduates:

- possess the necessary knowledge and comprehension to identify, formulate and to solve problems, including aspects outside of their area of specialisation, by means of established or newly developed methods,
- are able to transform generally formulated tasks into feature-oriented requirement profiles and conduct a scientifically based analysis by applying learned methods,
- are able to apply their knowledge and comprehension to analyse developments (material characteristics, products, processes, methods), advance these developments and communicate these to others,
- are in the position to apply various methods – mathematical analysis, computer-aided designs or systematic experimental research – to conduct task-specific analyses and/or independently resolve issues of development tasks.
- Are able to select and apply suitable analysis and modelling techniques

**Development**

Development encompasses the entire development process up to the accomplishment of a technical project objective. Objectives of a development process are, for instance, applicable products, devices, processes and methods, but also material features that are adapted for a specific purpose. Development processes also include consideration of ethical, social, health, safety, ecological and economic conditions.

Graduates:

- are able to apply their knowledge and comprehension to conduct developments according to predefined and specific requirements, to realise results and do this in collaboration with a team of engineers, scientists and representatives of other subject areas,
• have learned fundamental development and planning methods and possess the competency to apply these systematically

Research and Evaluation
Graduates:
• are capable of carrying out literature and data research and use data banks and other sources of information
• have a solid command of methods and procedure to document research results,
• are able to conduct a comparative analysis between their own findings and results from theory and relevant literature, and to draw conclusions relevant to their interest.

Application
Successful practice requires a solid competency in knowledge and methodology, combined with practical experience in completing typical development tasks. Only this will lead to the effective and efficient development of solutions. A critical additional element is a profound knowledge of the fundamentals of natural science including sufficient theoretical knowledge. Only this will ensure targeted expansion of existing knowledge or be transferred onto new tasks. Furthermore, the cross-sectional character of the respective disciplines requires that experts of this subject area also possess fundamental knowledge of other engineering or applied sciences.

Part of the professional profile is also the ability to transfer independently acquired 'know-how' to other areas (technology transfer). This includes practical knowledge of:

• the applicability of technologies, the usability of materials and the applicability of processes as well as their possible limitations,
• specific technologies, processes and procedures
• data processing, measurement engineering and experimental procedures, as well as the design of models
• technologies, processes and procedures, devices and tools that correspond to the specific focal points of the respective study areas
• practices in the production facility
• professionally and methodologically relevant literature and other sources of information

Graduates:
• are able to combine theory and practice to solve problems related to a setting of Physical Technology, Material Science or Material Engineering
• are able to initiate respective developments and justify their necessity
• are in a position to select and apply the necessary and suitable devices, tools (hard and software) and methods,
• have developed an understanding of applicable techniques and methods and their limita-
tions,

• apply safety technology

• are aware of the ethical and social implications of their actions

**Multidisciplinary Competencies**

Graduates¹:

• are able to work in teams and are able to constructively contribute as an individual and as a team member

• are able to apply various methods to communicate effectively with the engineering or scientific community and with any community in general

• are aware of the health, safety and legal implications and responsibilities of the engineering practice, as well as the implications resulting from technical-scientific solutions within a social and natural environment. Graduates also commit to appropriately act according to professional ethics, accountability and norms set by the technical-scientific practice.

• Are aware of the methods and limitations of project management and business practice, such as risk and change management

• Acknowledge the need and have the ability for independent and lifelong further learning

**2.2 Requirements for Master Degree programmes**

Building on an initial higher professional qualification, the Master Degree programme leads towards acquiring in-depth analytical, methodological and scientific competencies. At the same time, the acquired competencies from the first professional qualification programme are being expanded and broadened. This should be ensured through a suitable curricular structure and it should support the relevant research and development activities of the responsible faculty. A Master Degree programme can have an application orientation as well as a research orientation. Master Degree graduates should reach a level of knowledge and competency that in principle qualifies them for a doctorate degree in their area of specialisation.

**Knowledge and Comprehension**

Being in command of in-depth knowledge and comprehension of the Natural Sciences, Mathematics as well as the fundamentals of Technological Science and professional practice, are features of a Master Degree level and are necessary to achieve further educational results.

¹ Dieser Absatz folgt mit geringfügigen Modifikationen, Verein Deutscher Ingenieure (Hg.), Grundsätze für Ausbildungsergebisse ingenieurwissenschaftlicher Studiengänge (https://www.vdi.de/fileadmin/vdi_de/redakteur_dateien/bildung_dateien/Grundsaetze_fuer_Ausbildungsergebnisse.pdf (29.07.2016))
Graduates:

- Possess profound knowledge and in-depth comprehension of the subject-specific fundamentals of the main focus of their degree programme (theory and practice),
- Have advanced knowledge of related subject areas,
- Have developed a critical awareness of the new insights in their discipline
- Are informed about the current status of their subject area (‘status of technology’)

Analysis and Methodology

The analysis can include the identification of a problem, clarification of a specification, the consideration of possible solutions, the selection of the most suitable methods and their implementation. In order to execute these processes with the highest quality and to get results that are sufficient for further requirements, e.g. regarding the development status or a leadership position, scientifically based methods for executing these processes are broadly known. In a broader scope, they can be applied and if needed further developed according to problem specific requirements.

Graduates:

- possess the ability to independently identify, analyse and solve problems that are incompletely defined, that are uncommon and that in some cases exhibit contradictory specifications
- are able to apply innovative methods in solving technological problems
- are able to formulate and solve problems within a new or developing area of their specialisation
- are in the position to apply their knowledge and comprehension to design complex scientific models, systems and processes
- are in the position to apply and further develop various methods. This includes, for instance, mathematical scientific analyses, model design and execution of precise experimental research.

Development

Development activities can refer to devices, processes, methods, models and materials. Beyond scientific and technological aspects, the specifications can involve the consideration of social, health and safety, ecological and economical requirements.

Graduates:

- are in the position to realise technical scientific designs while collaborating with engineers, scientists and representatives of other subject disciplines,
- are able to apply their knowledge and comprehension in order to develop solutions to complex problems, and also by integrating other disciplines
are able to apply their creativity to develop new and original ideas and methods

are able to apply their scientific judgement to gather, process and/or augment incomplete information in order to solve complex and technical challenging problems in such a way that it justifies their use while respecting scientific but also ecological aspects,

are in the position to develop and/or optimise systems, processes or methods based on their acquired knowledge,

are able to independently develop and apply their knowledge later within their professional practice.

Research and Evaluation

Graduates:

are in the position to apply suitable methods to conduct systematically complex investigations or detailed research. They are in the position to independently expand their knowledge and learning as required,

are able to explicitly identify and evaluate the information needed, to localise the information (e.g. literature research, patent research, etc.) and to acquire it,

they can define and conduct investigations that utilise the means of analysis, modelling and experiments,

are able to critically evaluate data and draw conclusions,

are able to investigate and evaluate the applicability of newly emerging technologies in their discipline.

Application

Successful practical work requires practical experience with typical issues, in order to either further develop or newly develop effective solutions.

Graduates possess practical skills to solve problems. These include practical knowledge of:

the applicability of materials and methods,

simulations,

engineering and scientific processes, devices and tools,

the practice in research, development and production,

the state of the art in research and technology.

Graduates:

are able to combine theory and practice in order to solve scientific or technological problems
• are able to combine knowledge and learning from various areas and to cope with complex issues,

• have comprehensive knowledge of applicable technologies and methods and their limitations,

• know the non-technological implications of the work of engineers and scientists, particularly the safety, social and ethical consequences of their activities.

**Multidisciplinary Competencies**

Graduates:

• meet all the requirements of a Bachelor degree, regarding the key qualifications necessary for the higher level Master degree,

• are able to lead a team that can be comprised of various disciplines and levels,

• are able to effectively work and communicate in a national and international context,

• are in the position to recognise and evaluate the social, ethical, ecological and economic implications, as well as the basic requirements of their projects,

• should be in the position to evaluate their projects regarding occupational safety and work conditions and take precautions to prevent accidents.

### 3 Curriculum

The learning objectives for a given degree programme should be attained by means of an adequate content structure of the programme. Only through this kind of goal-oriented curriculum planning is it possible to realise the most important characteristics of Bachelor and Master Degree programmes. A critical feature of Bachelor Degree programmes is to achieve a professional qualification. In a Master Degree programme however, the ability to carry out scientific work is at the forefront.

The interdisciplinary character and the focus on content in programmes in Physical Technologies, Material Science and Material Technology requires at a minimum the following generically named subject areas, in order to acquire the desired learning outcomes of these programmes.

The structure of the specific curriculum should allow students to achieve the study objectives as defined by the institution.

#### 3.1 Bachelor Degree Programme in Physical Technologies

**Mathematical fundamentals including Informatics**

This includes Algebra, Analysis, Vector Calculus, Differential and Integral Calculus, functions of several variables, linear equation systems, mathematical methods of physics, introduction to Informatics, applied Informatics and electronic (measuring) data processing.
Fundamentals of Natural Sciences

This includes, inter alia, critical areas of experimental and applied Physics, as well as selected elements of theoretical Physics and fundamentals of Chemistry and Materials Science (related to building a focal area).

Subject-specific fundamentals

The content of engineering fundamentals forms the basis for the comprehension and engineering-based design and development of advanced subjects. Of importance for this are, for instance, engineering subjects such as Measurement and Control Engineering, Application of Micro-controllers, Production Technology, etc.

The subjects related to engineering fundamentals are ideally closely related to the focal points of the respective degree programme.

Also, subject-specific, fundamental scientific subjects follow the thematic focal points of the respective degree programme. This can include subjects such as, for instance, Laser Physics, Technical Optics or Acoustics, fundamentals of Ophthalmology, Medical Technology, Materials Science, Vacuum Technology, Surface and Thin Film Technology. Combined with the courses that are related to the advanced subjects of a programme focal point, these subjects form the content framework of a degree programme.

Specialisation subjects of a focal study

The elected focal point of studies should result in a degree programme with the necessary scope based on the fundamentals of Mathematics and Natural Sciences combined with the subject-specific fundamentals. This is also to achieve a sustainable acceptance within the professional field.

The subjects of a focal study offered expand or deepen the technological aspects from the subject-specific fundamentals. This may comprise courses such as Micro-system Technology, Sensor Technology, Environmental Technology, Laser Technology, Laser Applications (e.g. Laser Measurement Engineering, Laser Material Processing, Laser Systems Engineering), Plasma Technology, High Performance Materials, Manufacture and Treatment of Ceramics, Procedure in Plastics Processing, Fibre-reinforced Composites, Image Processing, Medical Hardware Technology, etc.

Non-technical subjects

These include, for instance, Foreign Languages, Business Economics, Work Techniques and Rhetoric, Marketing, Human Resources Management, Ethics, etc. These topics can also be taught within suitable technological modules.

Professional placement

The professional placement is typically completed in a suitable company or institution (domestic or abroad). It is important that the placement supports the engineering practice.

3.2 Master Degree Programmes in Physical Technologies

Science-oriented Master Degree programmes in Physical Technologies result in a subject-specific specialisation in the area of Mathematics and Natural Sciences. The subjects offered are again focused in detail on the respective focal point of the programme.
Examples are special areas of Mathematics, System Theory, Quantum Mechanics, Statistical Physics, Thermodynamics, Electric and Magnetic Fields, Currents and Solid State Physics.

For a Master Degree programme with an application orientation in Physical Technologies, the focus should be on subjects such as, for instance, Engineering Mathematics, Software Applications, programmes for the analysis of measuring results or the depiction and simulation of theoretical correlations and supplements to physics.

Depending on the institution’s profile, different focal studies in the Master Degree programme (e.g. Laser Technology, Microsystem Technology, Nano Technology, etc). These focal studies can be freely elected by the students. In this way, it is possible for the application orientation to ensure that the relevant specialisation subjects, e.g. in Engineering Sciences, lead to the achievement of the corresponding learning outcomes and development competencies. Along the same lines, specialisation subjects in a application orientation programme with a strong focus on research and fundamentals should ensure the achievement of relevant learning outcomes, e.g. regarding a larger extent of scientific analysis and working methodology.

3.3 Bachelor Degree Programmes in Materials Science and Technology

The Fundamentals of Mathematics and Natural Sciences

These include Mathematics, Physics (esp. Fundamentals of Solid State Physics), Chemistry.

Subject-specific Fundamentals

The contents of subject-specific fundamentals form the basis for the comprehension and for the design and further development of specialisation subjects.

For example, within the area of engineering, subjects such as Construction Theory Fundamentals, Applied Thermodynamics, Processing Technology, Materials Science and Technology are of critical importance. In the natural sciences sciences area, subjects such as Fundamentals of Crystallography, Bonding of Solid State, Phase Structure and the interaction between characteristics and micro structure. Moreover, knowledge of typical research methods of structure and characteristics is indispensable.

Subject-specific fundamental courses in Natural Sciences are focused on the thematic emphasis of the respective degree programme. This complex can, for instance, include subjects like fundamentals of Materials Science, Solid State Physics, Polymer Chemistry, Materials used in Electrical Engineering, Surface Chemistry and Surface Physics.

Together with the courses allocated to the advanced subjects in focal studies, these subjects form the structure of the contents of a degree programme.

Specialisation subjects in focal studies

The elected focal point of studies, based on the fundamentals of mathematics and natural sciences and in connection with the subject-specific fundamentals, results in a degree programme with the necessary scope and thus promotes a sustainable acceptance on the labour market.

The subjects offered in this field advance or deepen the technological aspects in the area of subject-specific fundamentals. This may include courses such as Structural Evaluation and Analysis, Solid State Analysis, Semi-conductor or Metal Physics, Manufacture and Treatment of Ceramics, Procedures of Plastics Processing, Composite Materials, Joining and Coating Technolo-

**Non-technical subjects**

These include, for instance, Foreign Languages, Business Economics, Work Techniques and Rhetoric, Marketing, Human Resources Management, Ethics, etc. These topics can also be taught within suitable technological modules.

**Professional Placement**

The professional placement is typically completed in a suitable company or institution (domestic or abroad). It is important that the placement supports the engineering practice.

### 3.4 Master Degree Programmes in Materials Science and Technology

All Master Degree programmes, both research-oriented and application-oriented, have a basis in advanced knowledge of mathematics, natural sciences and engineering in the area of materials physics, materials chemistry, materials development, materials application and modelling of materials characteristics.

Moreover, depending on the profile of the degree programme, a stronger implementation of software applications related to Natural Sciences and Technology is advisable.

Depending on the profile of the institution, different focal studies are offered in Materials Science, such as, for instance, in the area of Materials Engineering (Metallurgical Processes, Treatment and Processing, Application and Selection of Materials), Materials Characterisation and Evaluation, Materials Development or also the focus on individual groups of structure materials (e.g. ferrous metals, non-ferrous metals, polymers, ceramic materials) or functional materials (e.g. semi-conductors, magnets, superconductors, optical materials, bio materials). The orientation of a Master Degree programme (either research or application oriented) is reflected in its curricular structure. This makes it possible for advanced subjects in a practice oriented programme, for instance related to engineering, to ensure the achievement of the intended learning outcomes or competencies. Equally, advanced subjects of a research oriented degree programme that focus strongly on research and fundamentals, can ensure that the intended learning outcomes, for instance regarding scientific analysis, are achieved to a larger extent.

### 4 Types of Courses

The learning outcomes as outlined in paragraph 2 are not limited to professional knowledge and skills, but also include a significant portion methodological competencies such as social and interdisciplinary competencies.

As a rule, these cannot be achieved solely by the necessary courses with classical methods (lectures, exercises, tutorials, etc.), but additionally require an equally result-oriented, consistent course structure. Thus, it is advisable, for instance, to integrate non-subject related competencies into subject-related courses. This could be done, for example, by using a course form that is adapted for this purpose.

Examples for this are laboratories (scientific work, teamwork, documentation), seminars focusing on natural sciences or subject-specific seminars (scientific work, research, presentations, rhetoric, if necessary languages), project work (development, scientific work, research, team-
work, documentation), Blended Learning (online courses, group-based online learning) and project-focused education (guided and organised group work, laboratory practice, web-based support).