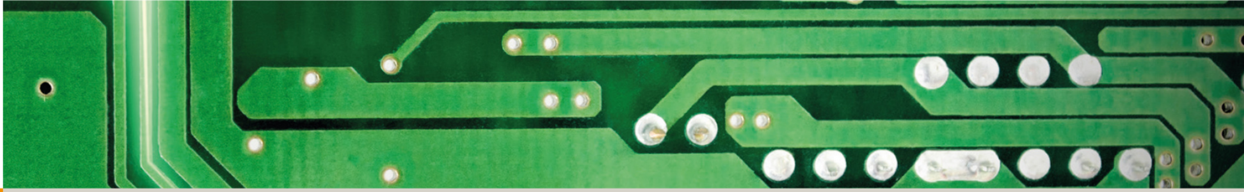


3TU.

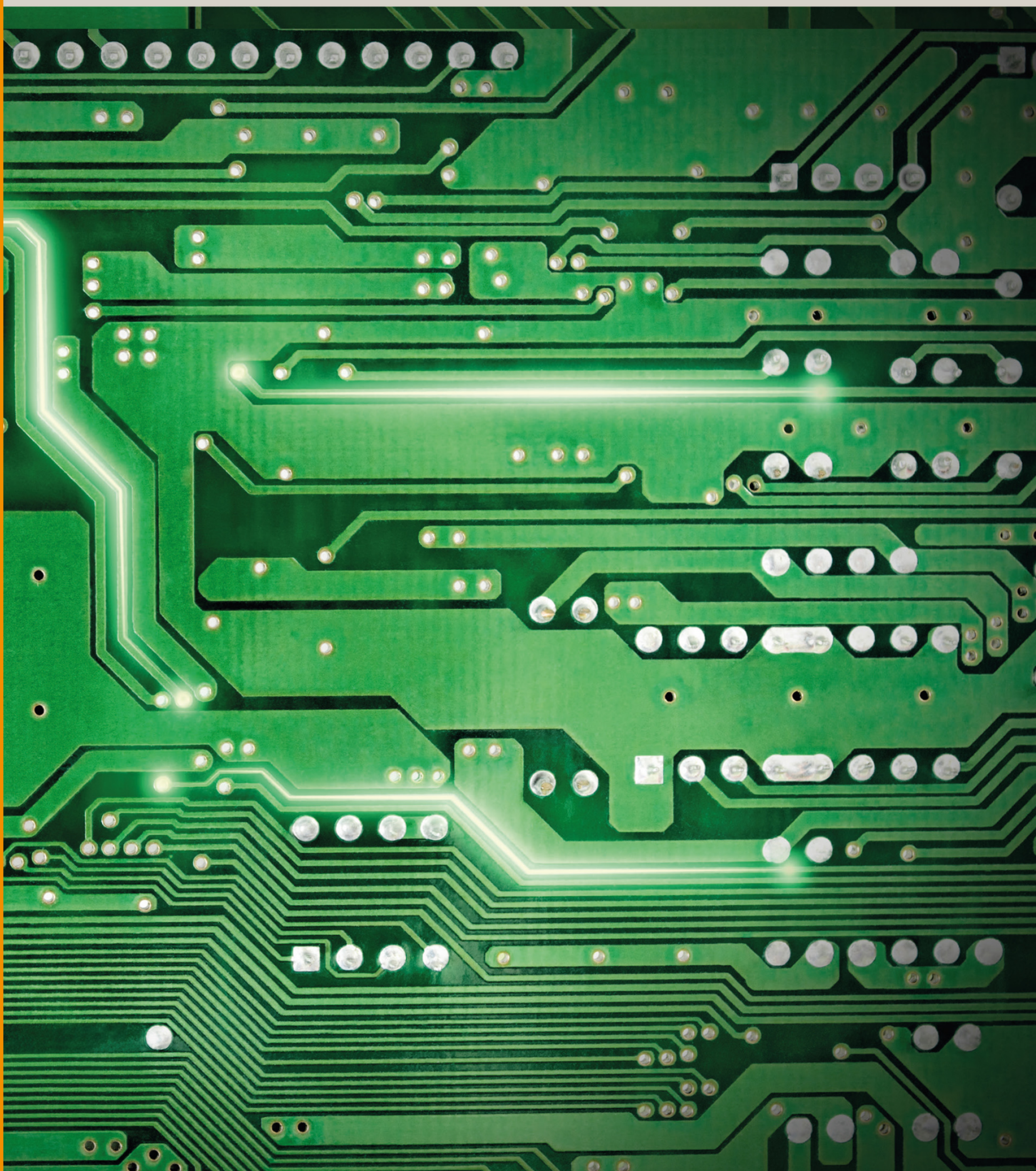
TU Delft
TU Eindhoven
U Twente

Domain Specific Frame of Reference Electrical Engineering

TU Delft Delft University of Technology

TU/e Technische Universiteit Eindhoven University of Technology

UNIVERSITY OF TWENTE.



Domain Specific Frame of Reference
Electrical Engineering

July 2016

This updated Domain-Specific Frame of Reference (DSFR) is based on the version used for the previous external review, which was reported by QANU in 2010. The 2016-DSFR is more concise than the 2010-version: only the consolidated requirements are now included.

Source information was updated for this 2016-DSFR. Also, some additional literature search was carried out, primarily focusing on requirements from the professional field.

The ABET 2016-2017 criteria [3] –general as well as specific to Electrical, Computer, Communications, Telecommunication(s) and similarly named Engineering Programmers– appear to contain no major changes. We have also reviewed ASIIN's [4] renewed subject benchmark statement on Electrical Engineering and Information Technology of 2011.

Several changes were made to the consolidated graduates' requirements in Table 1 (Bachelor's). Generally speaking, there is considerable consensus between ABET (USA) and ASIIN (Germany) criteria. In addition to these international requirements, we will use the Meijers criteria [7] (see Section 9 at page 17) as a reference in the Critical Reflections.

This document was prepared in LaTeX in the TeXShop environment, using the Carlito font.

Contents

Domain Specific Frame of Reference

1 Introduction

Literature searches in 2010 and again in 2015 did not unveil an existing authoritative domain-specific framework of reference for Electrical Engineering (EE). Therefore, this proposal for a DSFR for the assessment of the academic bachelor's and master's programmes of Electrical Engineering was developed by the programme management of 3TU (Technical Universities of Delft and Eindhoven and the University of Twente, Enschede) in The Netherlands. The purpose of this document is to provide an overview of requirements for EE graduates and programmes as a reference for the Critical Reflections. It consists of the following parts:

- A brief overview of the domain of Electrical Engineering in Section 2. Computer Engineering (CE) is considered a distinct part of EE. Almost everywhere in this document where reference is made to EE, this can be read as EE *and* CE.
- Requirements for *graduates* of programmes in this domain (bachelor's and master's) (Section 3)
  - Academic requirements
  - Professional requirements
- Requirements for *programmes* in this domain (Section 4)
  - Academic requirements
  - Professional requirements
- Motivation and sources used. Please note that the section on motivation and sources will be covered mainly in conjunction with the requirements sections.

2 The domain of Electrical Engineering

Text from the 'Joint note of the deans of EE, appendix of the midterm review EE 2015'

"Electrical Engineering plays a key role in the global economic growth. Nine out of twelve potentially disruptive technologies listed by McKinsey in 2013 [1], [2] are directly connected to EE: the mobile internet, the internet of things, advanced robotics, autonomous and near autonomous vehicles, next generation genomics, energy storage, 3D printing, advanced oil and gas exploration and recovery, renewable energy. Materials science, physics, electronics, photonics, computer engineering and computer science are becoming more connected or overlapping and they blend with application areas such as energy, healthcare, mobility and transport, safety and security, leisure and sport."

Time Magazine recently published a list of the '50 Most Influential Gadgets of All Time', ranging from the Google Glass (#50) to the iPhone (#1). 48 out of these 50 'gadgets' are directly related to electrical engineering. The list of EE related devices includes the Segway, drones, Raspberry Pi, PC, laptop, Fitbit, Commodore64, Deskjet printer, mobile phone, Play Station, Walkman, iPod, iPad, TomTom, camcorder, video recorder, IBM Selectric Typewriter, WiFi modem, etc. Electrical Engineering has more impact on society than ever before. *Every 'intelligent' device is based on the work of electrical engineers. They use physics, mathematics and inventiveness to design the technology of the future*" [5].

Every 'intelligent' device is based on the work of electrical engineers

Electrical Engineering concerns almost all technology related to information (telecommunication, computers, phones, television, radio, internet, newspapers, travelling, military) and to energy (‘classical’ electrical energy from fossil fuel, new technology for sustainable energy from sun, wind, water, its generation, storage, conversion, control and transport) and the link between these two domains (Figure 1.2). As a discipline, Electrical Engineering studies, explores and analyses physical phenomena on the scale of atoms (quantum computers, nano-machines) up to a scale larger than earth (aerospace). Some are quite simple, such as the movement of electrons, but others are on the verge of what humans can grasp, such as the design of integrated circuits, or the design of a fusion reactor. Some technology is straightforward and almost obsolete, like the plain light bulb, other technology is unimaginably complex, like the connection between computers and the human brain. Whatever the aspect of life, technology’s impact on it has been steadily increasing, and this trend is expected to continue. As a result, society as a whole is in need of a growing number of electrical engineers, and job opportunities structurally reflect this need.

Apple’s iPhone

Apple has demonstrated that the integrated design of a complete system where hardware and software are combined into a beautiful product is a formula for success. Before the iPhone, mobile phones were already advanced devices for communication. But the iPhone is much more. It combines hardware in the form of (digital) electronics, sensors and actuators, video cameras, GPS and easy-to-use software in the form of apps all together in a beautiful design. A design, so user-friendly, that small children and elderly people can use it, almost without any instructions. The iPhone combines all the domains of electrical engineering including power electronics, where increasing the capacity and life time of the battery is still an important challenge. The smart phone in general also demonstrates where the availability of small and inexpensive components can lead to. The computer power of a main frame of a few decennia ago is now in one’s pocket and is enhanced with high-quality photo cameras, a satellite navigation system, and many more features. It offers worldwide video calls, almost for free. The only limit seems to be the imagination of designers. “If the iPhone would have been built with the technology of less than 50 years ago –with discrete transistors rather than chips– it would be 10 meters thick and have the height of the Eiffel tower. In addition, it would require a nuclear power station to operate” (prof. Bram Nauta, Dies rede UT, 2013).

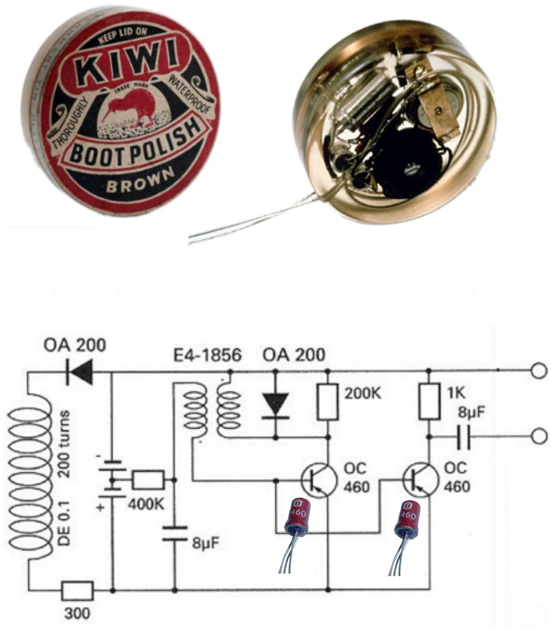
Tesla/Google Car

The modern car is an intelligent system, super high-tech. Electrical components are here to stay with the transition to new powertrains (hybrid and electric) and advances in communication and navigation. In addition to the traditional mechanical engineering, the emphasis lies increasingly on disciplines like electronics and software. “There are more than enough challenges: the automatic gearbox, improving energy management systems and drivability versus economy. Human technology interaction increases also. Such as the steering wheel that vibrates if the driver appears to be falling asleep at the wheel or the car that brakes when the navigation system indicates an imminent red light. Intelligent software will soon comply with all the user’s wishes. In 2040 we will be driving electric cars that come right up to the front door and adapt their interior to match your mood. They will be fully automated, going from Point A to Point B by the most efficient route, with safety and comfort guaranteed” (prof.dr.ir. Maarten Steinbuch, Automotive Technology, TU/e).

photo: Bart van Overbeeke

Electroceuticals

The world's first active implantable medical device, a cardiac pacemaker developed by Rune Elmqvist, an engineer, and Åke Senning, a surgeon, was implanted in Sweden on October 8, 1958. To package the implantable pulse generator they used a Kiwi shoe polish box as a mold for a new epoxy resin, which had excellent biocompatibility. The epoxy housed a nifty 'blocking oscillator' circuit that delivered impulses at a rate of 70 beats per minute. It contained two of the world's first silicon transistors, which were much more efficient than the germanium transistors used in other electronic circuits. Arne Larsson, the patient that underwent the surgery had 22 pulse generators implanted until his death in December 2001, aged 86, surviving both the engineer and the surgeon who saved his life.
Modern cardiac pacemakers adapt their pacing rates to the activity and needs of the patients and can treat a wide range of cardiac arrhythmia. They use silicon chips, various biosensors and can be controlled and programmed wirelessly. Currently, more than 700,000 pacemakers and implantable cardio-defibrillators are implanted worldwide every year. Pacemaker-like devices successfully treat patients for neural disorders like Parkinson, dystonia, chronic pain, etc. thereby allowing them to lead healthy lives again. The latest descendants of pacemakers are the so-called 'electroceuticals', the electronic counterparts of pharmaceuticals, which listen and talk to the body by means of electricity. They already allow the deaf to hear again, the blind to see again and will allow for the treatment of an even larger range of neuronal and brain disorders. The medicine of the future you will have to take only once and it will be an electroceutical.
(prof.dr.ir. Wouter Serdijn, TUD, inaugural speech, 2016)



The development of intelligent devices and systems in the form of smart phones, automatic cars, health-care systems, domotica and robotics is the result of advances in electrical engineering and will continue to have a considerable impact on society.

The Institute of Electrical and Electronics Engineers (IEEE) is "the world's largest technical professional society –promoting the development and application of electrotechnology and allied sciences for the benefit of humanity, the advancement of the profession, and the well-being of its (425 000) members." The domain of EE is best represented by a list of the IEEE professional societies (See the appendix in Section 8) and in more detail by their journals, transactions, letters and magazines. No educational programme can reasonably cover all these subareas explicitly, so the aim must be to teach a core programme that enables graduates to specialise in any of them, within boundaries of time and effort that are considered adequate by peers and specialists.

Figure 1.1 summarises this. Based on the core disciplines in the inner circle, EE is about 'information and signal processing' (in the information domain) and power (in the physical domain), and the interaction of these two (yellow circle). The blue circle indicates the basic disciplines of EE. Outside the circles a selection of the many domains of application of EE is provided.

A major part of electrical engineering deals with processing of information in electronics or in software. Electronic hardware and software can make all kinds of systems intelligent. The combination of these two is rapidly changing the world. The source of this information is often a sensor, which converts information from the real world into an electronic signal. In the dual case, the processed information should result in actions taken in the real world. This is often realised by means of actuators (e.g. in the form of an electrical motor in a robot). An actuator converts information in actions in the physical world, where (electrical) power plays a role. Power electronics, electrical machines and electrical power networks are parts of this side of the EE domain. This can be represented in the form of Figure 1.2. In this figure the pink area indicates the physical domain, where power is dominant, the blue are indicates the information domain where signal processing, control and optimisation are dominant.

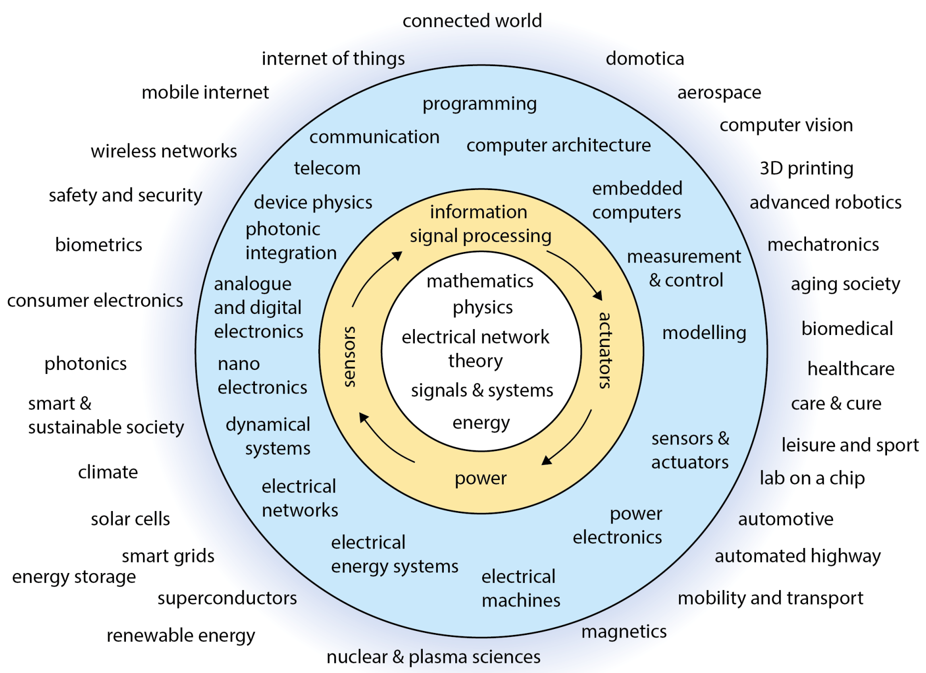


Figure 1.1 The domain of Electrical Engineering

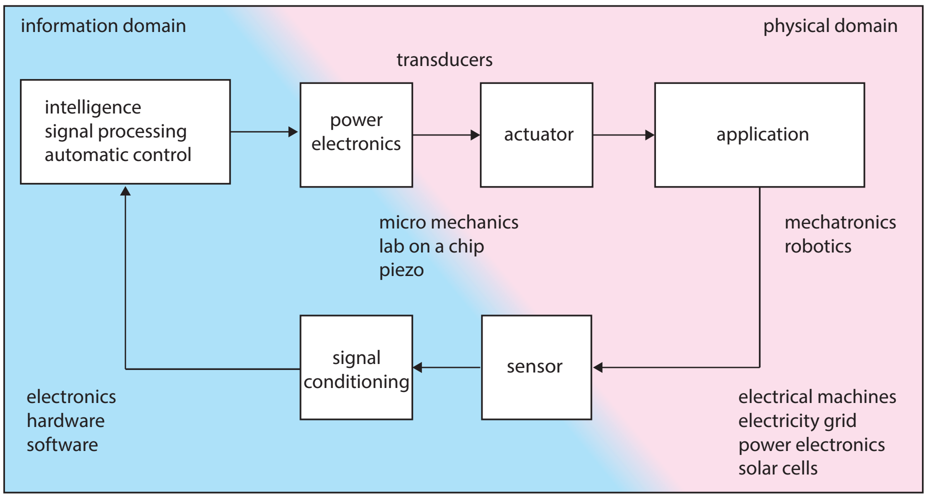


Figure 1.2 The physical and information domains of Electrical Engineering

Another view on the domain of the electrical engineer is given in Figure 1.3. This figure indicates that EE covers a wide range of disciplines, from materials and technology to systems and concepts and deals with physics as well as with information. Fields of engineering and science are shown along the horizontal direction, with a conventional annotation of the fields at the bottom and the names of seminal scientists in that field at the top.

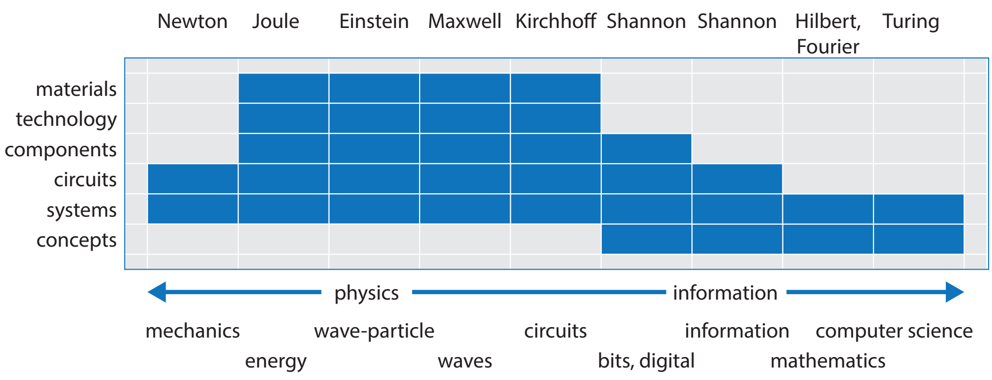


Figure 1.3 The domain of Electrical Engineering covers a wide range of disciplines

Please note the double occurrence of Shannon: his master's thesis founded the field of digital circuit design theory; later he wrote a landmark paper that founded the field of information theory.

Computer Engineering (CE) can be seen as an independent discipline or as sub-discpline of EE, with a close connection to the discipline of Computer Science (CS). Where CS can be understood to be the study of how computer systems are used, the CE discipline can then be understood to study how computer systems are designed and built. In terms of the visualisation of the domain in Figure 1.3, CE is placed in the columns indicated as 'circuits', 'bits, digital' and 'computer science'. With the currently developing research field in quantum computing, the 'information' column is indicative of exciting new developments in the field of Computer Engineering.
The intimate connection between Electrical Engineering and Computer Engineering is confirmed by noting that 12 out of 13 American universities in the top 25 of the Times Higher Education ranking in Engineering offer a CE Master's degree programme, sometimes in a combined EECE programme. The close relation with Electrical Engineering is also apparent in the fact that the IEEE covers the field through its Computer Society, being the largest of the 39 Societies of the IEEE. In Europe, ES (Embedded Systems) is more prevalent as a study than CE.

2.1 Typical courses in the EE curriculum

It is impossible to cover the whole spectrum of electrical engineering and all its applications in the programme of one student. The core of the BSc of EE is formed by (a selection of) the topics mentioned in the third (blue) circle in Figure 1.1:

- electrical networks
- dynamical systems
- analogue, digital and power electronics
- nano electronics
- device physics
- photonic integration
- telecommunication
- modelling
- measurement and control
- sensors and actuators (transducers)
- computer architecture
- programming
- embedded computers
- electrical energy systems
- electrical machines

Traditionally, electrical engineering was mainly related to analogue hardware. Consumer-electronics products, such as radios or TVs, were products with exclusive knowledge from the domain of EE. Nowadays, hardware is also present in the form of a 'computer' as a building block. Therefore, programming and experience with *embedded computers* should be part of an EE programme. Embedded computers enable adding *intelligence* in a flexible way: ICT and information technology are well established within the domain of EE as well.

Embedded computers

Intelligence

Because of the basic courses of EE in mathematics, electrical networks, dynamical systems and modelling, the electrical engineer is able to reason on a *high level of abstraction* when designing integrated hardware and software for intelligent systems and applications. Courses on modelling of multi-physical systems and control engineering develop system thinking and optimisation. This *systems approach* makes electrical engineers problem solvers, also of problems outside the domain of EE.

High level of abstraction

Systems approach

2.2 Challenges

Ethics and social sciences

Because of this interaction with the outside world, EE has many different, challenging applications. These applications and societal developments are indicated outside the circles of Figure 1.1. The transfer to a more electrical-power-based economy, stimulated by the 2015 agreement on climate change, imposes substantial challenges to electrical engineering: power generation from durable resources, dealing with variable supplies, smart grids, energy storage, transfer to electrical- or hydrogen-powered vehicles are just a few examples. Health-care applications and supporting the aging society with intelligent domestic robots and easy-to-use communication systems are other societal challenges. Also developments of the internet of things and domotica will change our world. Because all these developments will have a major impact on society, courses on *ethics and social sciences* must be part of the curriculum as well.

2.3 Impact on the EE curriculum

Multidisciplinary research

System thinking

The above-mentioned core courses of EE in the BSc programmes are essential for the education of electrical engineers. All lecturers should be involved in research as well to stimulate that recent developments from research projects find their way to the basic courses. Of course this impact is even higher in the more specialistic courses in the MSc curriculum.
A clear trend in research is the increasing need for combining expertise from multiple research domains. The need for *multidisciplinary research* requires strong collaboration among researchers and experts in different domains and solid team work with excellent communication skills between researchers. We see this need and actively stimulate team work, emphasise system thinking and train communication skills in the curriculum. The electrical engineer has been trained in *system thinking* and is able to apply knowledge on information technology, signal processing and automation in different fields or in collaboration with experts in different research domains.

3 Requirements for graduates in the domains of EE

3.1 Introduction

Requirements for BSc and MSc graduates

In this section, the *requirements for graduates* will be outlined. Bachelor's and master's requirements will be dealt with separately where appropriate. Three main categories of sources will be used:

1. Academic sources
2. Professional sources
3. Combinations of academic and professional sources.

ABET

ASIIN

Tuning-Ahelo

Meijers criteria

For this 2016-version of the DSFR, we used the same types of core sources. As to academic sources, a consortium-based set of qualifications for Electrical and Information Technology (IDEA League, 2005) was reviewed. The most recent criteria sets of *ABET*, [3] the USA engineering programme accreditation agency (engineering and electrical engineering) and of *ASIIN* [4], the German accreditation agency, were reviewed as a combined academic/professional source. Also, *Tuning-Ahelo* [6] was reviewed as a combined academic/professional source.
In the Critical Reflections we will also check the curriculum and the quality of our graduates against the *Criteria for Academic Bachelor's and Master's Curricula*, *also known as the Meijers criteria* [7] (see Section 9 at page 17). These criteria were developed especially for the three TUs in the Netherlands and approved by the NVAO.

3.2 Requirements for bachelor's graduates in Electrical Engineering

Requirements for BSc graduates

Based on a careful consideration of the criteria mentioned under 3.1, we derived a consolidated set of *requirements* for Bachelor's graduates in EE (provided in Table 1).

Table 1 Consolidated requirements set for Bachelor's graduates in EE

No.	Requirement	Source
1	an ability to apply knowledge of mathematics, science, and engineering	ABET, ASIIN
2	an ability to design and conduct experiments, as well as to analyze and interpret data	ABET, ASIIN
3	an ability to design a system, component, process or device/product to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability	ABET, ASIIN
4	an ability to function on multidisciplinary teams	ABET, ASIIN
5	an ability to identify, formulate, and solve engineering problems	ABET, ASIIN
6	an awareness and understanding of professional and ethical responsibilities that underpin their actions	ABET, ASIIN
7	an ability to communicate effectively	ABET
8	the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	ABET, ASIIN
9	a recognition of the need for, and an ability to engage in life-long learning	ABET, ASIIN
10	a knowledge of contemporary issues	ABET
11	an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	ABET, ASIIN
12	the ability to demonstrate a sound knowledge in the subject-specific fundamentals of electrical engineering, e.g.: • electrical networks • linear systems • analogue, digital and power electronics • nano electronics • device physics • telecommunication • modelling • measurement and control • sensors and actuators (transducers) • computer architecture • programming • embedded computers • electrical energy systems • electrical machines	ASIIN
	graduates of the BSc EE:	
13	… are capable of searching technical literature and other information sources	ASIIN
14	… demonstrate an awareness of project management and business practices, such as risk and change management, and understand their limitations	ASIIN
15	… are capable of communicating with colleagues and the general public about substantive issues and problems related to their chosen discipline, and can also communicate in foreign languages and at an intercultural level	ASIIN
16	… are able to work either independently or as a member of international and mixed-gender groups, effectively organise and conduct projects, and assume corresponding leadership responsibilities	ASIIN
17	… are well-prepared upon entering the workforce for the social and work requirements of the industry or academic context, as their course of study was sufficiently practice-oriented.	ASIIN

3.3 Requirements for master's graduates in this domain

Requirements for MSc graduates

Based on a careful consideration of the criteria mentioned under 3.1, we derived a consolidated set of *requirements* for Master's graduates in EE (provided in Table 2).

Table 2 Consolidated requirements set for Master's graduates in EE

No.	Requirement	Source
	graduates of the MSc EE	
1	knowledge and understanding: … have an in-depth knowledge in advanced fundamentals of mathematics and natural sciences	ASIIN
2	knowledge and understanding: … have in-depth knowledge in advanced subject-specific fundamentals of electrical engineering	ASIIN
3	knowledge and understanding: … have in-depth knowledge in one of the mentioned primary fields of application based on subject-specific fundamentals	ASIIN
4	engineering analysis: … can evaluate new complex modelling, measuring, design and test methods concerning their relevance, effectiveness and efficiency and can develop independently new methods	ASIIN
5	engineering design: … have specific skills for the design, development and operation of complex technical systems and services, thereby they … are capable to assembly the best components of these systems optimally as well as to evaluate the interaction of the systems with their environment, taking into account technical, social, economical and ecological aspects	ASIIN
6	investigations and assessment: … can develop suitable methods to make concepts, do and evaluate detailed research concerning technical topics	ASIIN
7	engineering practice and product development: **graduates are in the position to** … classify knowledge methodically in different areas, to combine information elements systematically, and to handle the phenomena of complexity … use and to develop their knowledge and skills in order to gain practical power for the solution of problems, for the organizing of research and the development of systems and processes, … classify knowledge methodically in different areas, to combine information elements systematically, and to handle the phenomena of complexity … use and to develop their knowledge and skills in order to gain practical power for the solution of problems, for the organizing of research and the development of systems and processes … familiarize quickly, methodically and systematically with new and unknown tasks … judge applicable methods and their limits … reflect systematically [on] non-technical implications of engineering work and to integrate the results responsibly in their actions … to develop marketable products for the global market	ASIIN
8	Transferable skills … control and organise complex, changing inter-relations of work and learning which require new strategic approaches … take over responsibility for scientific contributions to professional knowledge and to professional practice and/or … check the strategic capacity of teams.	ASIIN

4 Requirements for programmes in this domain

4.1 Introduction

Requirements for BSc and MSc programmes

In this section, the *requirements for programmes* will be outlined. Bachelor's and Master's programmes will be dealt with separately where appropriate. The same three main categories of sources will be used:

1. Academic sources
2. Professional sources
3. Combinations of academic and professional sources.

Diversity of educational practice is considered a strength of the discipline, according to e.g. QAA [8], the UK Quality Assurance Agency. In section 4.2 (Table 3) the requirements relevant to both Bachelor's and Master's programmes will be outlined. Thereafter, the Bachelor's (section 4.3, Table 4) and the Master's requirements (section 4.4, Table 5) will be dealt with.

4.2 Requirements for Bachelor's and Master's programmes

Note: The ABET 2016-2017 criteria also specify a range of general programme criteria such as 'student performance must be evaluated', and 'the program must have published program educational objectives'. Although very relevant in principle, we haven't included these as, in the Netherlands, they are covered by NVAO's programme accreditation criteria.

Table 3 Consolidated requirements set for Bachelor's and Master's programmes in EE

No.	Requirement	Source
1	The structure of the curriculum must provide both breadth and depth across the range of engineering topics implied by the title of the program The curriculum must include probability and statistics, including applications appropriate to the program name; mathematics through differential and integral calculus; sciences (defined as biological, chemical, or physical science); and engineering topics (including computing science) necessary to analyse and design complex electrical and electronic devices, software, and systems containing hardware and software components	ABET
2	The curriculum for programs containing the modifier 'electrical', 'electronic(s)', 'communication(s)', or 'telecommunication(s)' in the title must include advanced mathematics, such as differential equations, linear algebra, complex variables, and discrete mathematics The curriculum for programs containing the modifier 'computer' in the title must include discrete mathematics	ABET
3	An in-depth core of scientific and technical skills	IPENZ [9]
4	Sufficient breadth of experience in humanities and social, management, information and communications sciences (i.e. a complementing general education component)	IPENZ
5	Subjects should be studied formally in an ordered programme	IPENZ
6	Strategies for teaching, learning and assessment should deliver opportunities for the achievement of the learning outcomes, demonstrate their attainment and recognize the range of student backgrounds	QAA, also: NVAO
7	Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints	ASIIN
8	Bachelor's resp. Master's Thesis.	ASIIN

4.3 Requirements for Bachelor's programmes

Requirements for BSc programmes

Table 4 Consolidated requirements set for Bachelor's programmes in EE

No.	Requirement	Source
1	Bachelor's degree programmes on the one hand should qualify for a professional career, which means the possibility of an early career start in the fields of electrical engineering [and information technology], and on the other hand should qualify graduates also for further scientifically profound studies or for postgraduate studies not dealing with electronics or information technology	ASIIN
2	The development of a profile in electrical engineering takes place by the formation of a particular focus during general studies, discipline-specific studies and by the core areas of application. Possible core areas of application of the study subjects electrical engineering or information technology or the combination of both areas are e.g.: • Automation technology • Electronics • Power engineering • High-frequency engineering • Information transfer • Communication technology • Illumination Engineering • Mechatronics • Medical engineering • Microsystems engineering • Telecommunications technology • Technical informatics	ASIIN
3	(a) one year of a combination of college level mathematics and basic sciences (some with experimental experience) appropriate to the discipline (b) one and a half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the student's field of study. The engineering sciences have their roots in mathematics and basic sciences but carry knowledge further toward creative application. These studies provide a bridge between mathematics and basic sciences on the one hand and engineering practice on the other. Engineering design is the process of designing a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs. (c) a general education component that complements the technical content of the curriculum and is consistent with the program and institution objectives	ABET
4	Students will devote approximately 10% of their workload to general education subjects relevant for the engineering profession such as law, economics, management, sociology, environmental and ethical aspects, history of technology	IDEA League
5	The technical laboratory is embedded into the study programme as a practical phase, which must be scientifically supervised.	ASIIN

4.4 Requirements for Master's programmes

Table 5 Consolidated requirements set for Master's programmes in EE

Requirements for MSc programmes

No.	Requirement	Source
1	The criteria for masters level programs are fulfilment of the baccalaureate level general criteria, fulfilment of program criteria appropriate to the masters level specialization area	ABET
2	The program must demonstrate that graduates have an ability to apply masters level knowledge in a specialized area of engineering related to the program area	id.
3	The concrete designing of the Master's degree programmes is orientated on the specific strengths of the respective universities	ASIIN
4	The creation of a profile for the courses in electrical engineering or information technology is based on focal fundamentals, especially as to advanced specific fundamentals of electrical and information engineering as well as the focal points of application mentioned before [= the areas in Table 4 point 2]	id.
5	In an industry placement forming part of the degree programme, the technical and methodical competences gained at university level are to be applied to, extended and deepened in an industrial environment within the framework of typical engineering activities. Preferred fields are i.a. [inter alia] development, construction, planning and application technology	ASIIN
6	If the students are free to prepare individual study schedules, the university employs means for ensuring a technically sensible com-position of the individual schedules in line with the level and intended competence profile of the relevant degree	ASIIN
7	The curricula of Master's degree programmes reflect the specific R&D competence of the respective university and consistently operate on Master's level	ASIIN
8	In the decision upon the admission to Master's degree programmes in particular the applicants' individual skills are considered. Suitable measures are taken for applicants who are not qualified to a sufficient extent, to achieve such qualification	ASIIN
9	The domain and subject-specific skills and competences attained at master's level build upon the skills and competences at bachelor's level. The master phase of the programme provides a high level of specialization, a research related training and in-depth domain-specific knowledge at a professional level. Since the master phase is aimed at specialization and offers many choices, a global list of subject-specific competences for a master cannot be provided here.	IDEA League

5 Professional requirements

Our recent search made us identify papers from various scholars. Specifically, Davis et al.'s 2005 paper [10] is of interest to this DSFR. This paper covers engineering education as a whole. Their Table 1 is reproduced here:

Attribute	Mean Score	Overall Rank
Technically Competent	2.0	1
Communication Competent	3.9	2
Profound Thinker	4.1	3
Solution Driven	4.3	4
Professionally Responsive	5.4	5
Client Dedicated	5.6	6
Process Proficient	6.3	7
Empowering Others	6.8	8
Contextually Astute	8.1	9
Future Oriented	8.3	10

Table 6 Attribute Importance Rankings for Original Profile

Also, the 2012 paper by Rajalla [11], fellow of the IEEE, proved informative. Rajalla discusses the need for a 6th major shift in engineering education: the integration of attributes of a global engineer. This is depicted in Figure 1.4.

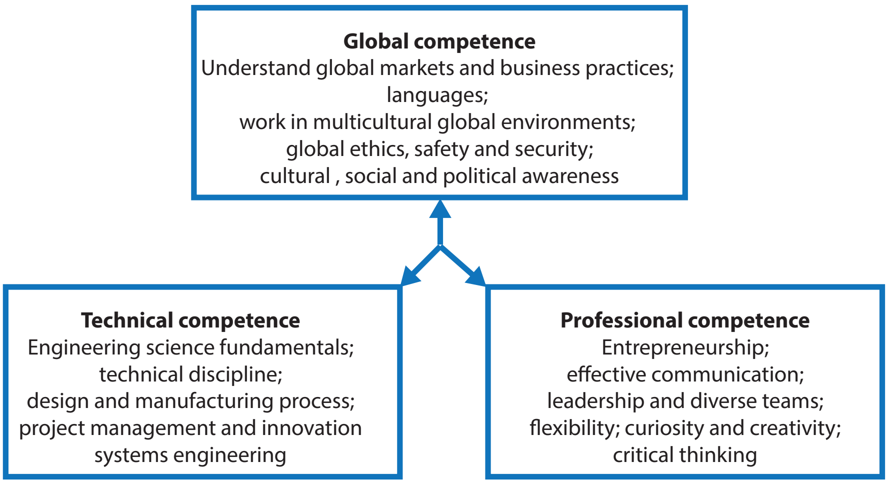


Figure 1.4 Atribures of a global engineer
Adapted from Y. Chang, D. Atkinson and E.D. Hirleman, 'International Research and Engineering Education: Impacts and Best Practices', Online Journal for Engineeing Global Education, Vol4, Issue 2, 2009

Top five attributes

The *top five attributes* for global competence were:

- can appreciate other cultures;
- is proficiently working in or directing a team of ethnic and cultural diversity;
- is able to communicate across cultures;
- has had a chance to practice engineering in a global context;
- can effectively deal with ethical issues arising from cultural or national differences.

6 Motivation and sources

As was the case with the 2010 DSFR, it proved very hard to obtain authoritative source materials from both the 'pure' academic perspective, and the 'pure' professional perspective. As a result, the same approach was taken, i.e. to use accreditation agency domain criteria. The rationale is, that in third-party accreditation criteria documents, the voices of both academia and industry are reflected. Two criteria sets, from accreditation agencies, were found to be rich inputs for this DSFR: ABET's 2016-2017 general requirements for engineering programs and Program criteria for Electrical, Computer, Communications, Telecommunication(s) and similarly named Engineering Programs, and ASIIN's 2011 criteria for Electrical Engineering and Information Technology.
ABET –from the USA– and ASIIN –from Germany– were found to provide a good common basis. In our view this adds value to the international coverage of this DSFR. We note here that in the USA university education differs from that in the Netherlands.

7 Summary of Source information

7.1 Programme requirements

General

IPENZ states:

IPENZ

"Professional engineering is the timely, methodical, disciplined and conscientious application of scientific, technical and management skills in a socially, economically, ethically and aesthetically aware way, for the benefit of society. Accordingly, the initial education of a professional engineer should provide an in-depth core of scientific and technical skills together with sufficient breadth of experience in the humanities and social, management, information and communication sciences to ensure a continuing awareness of these disciplines. Subjects should be studied formally in an ordered programme."

Bachelor's

The 2006 QAA Subject benchmark statement for Bachelor's programmes with honours [8] states: QAA
Existing engineering programmes have been developed over many years and deploy a diverse range of learning, teaching and assessment methods to enhance and reinforce the student learning experience. This diversity of practice is a strength of the discipline. Whichever methods are employed, strategies for teaching, learning and assessment should deliver opportunities for the achievement of the learning outcomes, demonstrate their attainment and recognise the range of student backgrounds. The methods of delivery and the design of the curriculum should be updated on a regular basis in response to generic and discipline-specific developments, taking into account educational research, changes in national policy, industrial practice and the needs of employers.

The ASIIN criteria indicate: ASIIN criteria
Bachelor's Degrees are on the one hand to facilitate professionally qualifying studies in electrical or information engineering together with early professional careers (professional qualification) and on the other hand are to qualify the graduates for advanced scientific degree programmes or additional degree programmes other than in electrical or information engineering. The creation of a profile for programmes in electrical and information engineering is based on focal fundamentals, especially as to advanced specific fundamentals of electrical and information engineering as well as focal points of application. Possible focal points of application of degree programmes in electrical and information engineering or a combination of the two are, for instance:

- Automation technology
- Electronics
- Power engineering
- High-frequency engineering
- Information transfer
- Communication technology
- Illumination Engineering
- Mechatronics
- Medical engineering
- Microsystems engineering
- Telecommunications technology
- Technical informatics

The ABET criteria state: ABET criteria
The curriculum requirements specify subject areas appropriate to engineering but do not prescribe specific courses. The faculty must ensure that the program curriculum devotes adequate attention and time to each component, consistent with the outcomes and objectives of the program and institution. The professional component must include:

a) one year of a combination of college level mathematics and basic sciences (some with experimental experience) appropriate to the discipline

b) one and one-half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the student's field of study. The engineering sciences have their roots in mathematics and basic sciences but carry knowledge further toward creative application. These studies provide a bridge between mathematics and basic sciences on the one hand and engineering practice on the other. Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs

c) a general education component that complements the technical content of the curriculum and is consistent with the program and institution objectives. Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints.

Bachelor and/or Master

"The competences and the associated dimensions [of the *Meijers criteria*] can be used in many ways in university education. Firstly, they not only describe the characteristics of a university graduate, but they also provide the basis for the *generic* learning targets of a university curriculum. After all, Meijers criteria academic programmes aim at educating people who have developed these competences to a certain level. In addition, they can be used as a conceptual and judgmental framework in the development, description, analysis, and evaluation of programmes. They can also serve as a source of inspiration for the determination of learning targets of individual courses. A very different type of use is the articulation of the academic *profile* of a programme. The areas of competence will not have the same relevance for all university programmes. The area of competence *designing*, for example, will play a more important role at a technological than at a general university. This means that programmes can define essential aspects as well as minimum levels in terms of academic competences."

ABET criteria

The ABET program criteria apply to engineering programs that include electrical, electronic, computer, or similar modifiers in their titles. The structure of the curriculum must provide both breadth and depth across the range of engineering topics implied by the title of the program. The program must demonstrate that graduates have: knowledge of probability and statistics, including applications appropriate to the program name and objectives; and knowledge of mathematics through differential and integral calculus, basic sciences, computer science, and engineering sciences necessary to analyze and design complex electrical and electronic devices, software, and systems containing hardware and software components, as appropriate to program objectives.
Programs containing the modifier 'electrical' in the title must also demonstrate that graduates have a knowledge of advanced mathematics, typically including differential equations, linear algebra, complex variables, and discrete mathematics. Programs containing the modifier 'computer' in the title must also demonstrate that graduates have a knowledge of discrete mathematics.

Master

ABET criteria

The ABET 2009-2010 criteria indicate:
Masters level programs must develop, publish, and periodically review, educational objectives and program outcomes. The criteria for masters level programs are fulfilment of the baccalaureate level general criteria, fulfilment of program criteria appropriate to the masters level specialization area. The program must demonstrate that graduates have an ability to apply masters level knowledge in a specialized area of engineering related to the program area.

ASIIN criteria

The ASIIN criteria indicate:
The Master's degree programme is based on a Bachelor's degree programme and offers technical consolidation either in the original focal application point of the Bachelor's degree programme (consecutive Master's degree programme) or in a different subject (non-consecutive or Master's degree programme in the form of a further education course). The concrete designing of the Master's degree programmes should be orientated on the specific strengths of the respective universities. The decision upon admission to Master's degree programmes should not solely be based on the individual qualifications of the applicants. The creation of a profile for the courses in electrical and information engineering is based on focal fundamentals, especially as to advanced specific fundamentals of electrical and information engineering as well as the focal points of application mentioned before (in section 2.1 of ASIIN's criteria document).

8 Appendix: IEEE Societies

IEEE (Institute of Electrical and Electronics Engineers) is "the world's largest technical professional society –promoting the development and application of electrotechnology and allied sciences for the benefit of humanity, the advancement of the profession, and the well-being of its (425 000) members."
The domain of EE is best represented by a list of the IEEE professional societies and in more detail by their journals, transactions, letters and magazines. No educational program can reasonably cover all these subareas explicitly, so the aim must be to teach a core that enables graduates to specialize in any of them, within time and effort boundaries considered by peers and employers to be adequate.

IEEE Aerospace and Electronic Systems Society
IEEE Antennas and Propagation Society
IEEE Broadcast Technology Society
IEEE Circuits and Systems Society
IEEE Communications Society
IEEE Components, Packaging, and Manufacturing Technology Society
IEEE Computational Intelligence Society
IEEE Computer Society
IEEE Consumer Electronics Society
IEEE Control Systems Society
IEEE Dielectrics and Electrical Insulation Society
IEEE Education Society
IEEE Electron Devices Society
IEEE Electromagnetic Compatibility Society
IEEE Engineering in Medicine and Biology Society
IEEE Geoscience and Remote Sensing Society
IEEE Industrial Electronics Society
IEEE Industry Applications Society
IEEE Information Theory Society
IEEE Instrumentation and Measurement Society
IEEE Intelligent Transportation Systems Society
IEEE Magnetics Society
IEEE Microwave Theory and Techniques Society
IEEE Nuclear and Plasma Sciences Society
IEEE Oceanic Engineering Society
IEEE Photonics Society
IEEE Power Electronics Society
IEEE Power & Energy Society
IEEE Product Safety Engineering Society
IEEE Professional Communication Society
IEEE Reliability Society
IEEE Robotics and Automation Society
IEEE Signal Processing Society
IEEE Society on Social Implications of Technology
IEEE Solid-State Circuits Society
IEEE Systems, Man, and Cybernetics Society
IEEE Technology and Engineering Management Society
IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society
IEEE Vehicular Technology Society

9 Appendix: Meijers criteria

The Meijers criteria in this document are a copy of those given in:
'Criteria for Academic Bachelor's and Master's Curricula', also known as the 'Meijers criteria' [7]

1 Competent in one or more scientific disciplines

A university graduate is familiar with existing scientific knowledge, and has the competence to increase and develop this through study.

	Bachelor	Master
a	Understands the knowledge base of the relevant fields (theories, methods, techniques). [ks]	Has a thorough mastery of parts of the relevant fields extending to the forefront of knowledge (latest theories, methods, techniques and topical questions). [ks]
b	Understands the structure of the relevant fields, and the connections between sub-fields. [ks]	Looks actively for structure and connections in the relevant fields. [ksa]
c	Has knowledge of and some skill in the way in which truth-finding and the development of theories and models take place in the relevant fields. [ks]	Has the skill and the attitude to apply these methods independently in the context of more advanced ideas or applications. [ksa]
d	Has knowledge of and some skill in the way in which interpretations (texts, data, problems, results) take place in the relevant fields. [ks]	Has knowledge of and some skill in the way in which interpretations (texts, data, problems, results) take place in the relevant fields. [ks]
e	Has knowledge of and some skill in the way in which experiments, gathering of data and simulations take place in the relevant fields. [ks]	Has the skill and the attitude to apply these methods independently in the context of more advanced ideas or applications. [ksa]
f	Has knowledge of and some skill in the way in which decision-making takes place in the relevant fields. [ks]	Has the skill and the attitude to apply these methods independently in the context of more advanced ideas or applications. [ksa]
g	Is aware of both the presuppositions of the standard methods and their importance. [ksa]	Is able to reject on standard methods and their presuppositions; is able to question these; is able to propose adjustments, and to estimate their implications. [ksa]
h	Is able (with supervision) to spot gaps in his / her own knowledge, and to revise and extend it through study. [ks]	Idem, independently. [ksa]

k = knowledge
s = skills
a = attitude

2 Competent in doing research

A university graduate has the competence to acquire new scientific knowledge through research. For this purpose, research means: the development of new knowledge and new insights in a purposeful and methodical way.

k = knowledge
s = skills
a = attitude

	Bachelor	Master
a	Is able to reformulate ill-structured research problems. Also takes account of the system boundaries in this. Is able to defend the new interpretation against involved parties. [ksa]	Idem, for problems of a more complex nature. [ksa]
b	Is observant, and has the creativity and the capacity to discover in apparently trivial matters certain connections and new viewpoints. [ksa]	Idem, and is able to put these viewpoints into practice for new applications. [ksa]
c	Is able (with supervision) to produce and execute a research plan. [ks]	Idem, independently. [ks]
d	Is able to work at different levels of abstraction. [ks]	Given the process stage of the research problem, chooses the appropriate level of abstraction. [ksa]
e	Understands, where necessary, the importance of other disciplines (interdisciplinarity). [ka]	Is able, and has the attitude to, where necessary, draw upon other disciplines in his or her own research. [ksa]
f	Is aware of the changeability of the research process through external circumstances or advancing insight. [ka]	Is able to deal with the changeability of the research process through external circumstances or advancing insight. Is able to steer the process on the basis of this. [ksa]
g	Is able to assess research within the discipline on its usefulness. [ks]	Is able to assess research within the discipline on its scientific value. [ksa]
h	Is able (with supervision) to contribute to the development of scientific knowledge in one or more areas of the disciplines concerned. [ks]	Idem, but independently. [ksa]

3 Competent in designing

As well as carrying out research, many university graduates will also design. Designing is a synthetic activity aimed at the realisation of new or modified artefacts or systems, with the intention of creating value in accordance with predefined requirements and desires (e.g. mobility, health).

	Bachelor	Master
a	Is able to reformulate ill-structured design problems. Also takes account of the system boundaries in this. Is able to defend this new interpretation against the parties involved. [ksa]	Idem, for design problems of a more complex nature. [ksa]
b	Has creativity and synthetic skills with respect to design problems. [ksa]	Idem. [ksa]
c	Is able (with supervision) to produce and execute a design plan. [ks]	Idem, independently. [ks]
d	Is able to work at different levels of abstraction including the system level. [ks]	Given the process stage of the design problem, chooses the appropriate level of abstraction. [ksa]
e	Understands, where necessary, the importance of other disciplines (interdisciplinarity). [ks]	Is able, and has the attitude, where necessary, to draw upon other disciplines in his or her own design. [ksa]
f	Is aware of the changeability of the design process through external circumstances or advancing insight. [ka]	Is able to deal with the changeability of the design process through external circumstances or advancing insight. Is able to steer the process on the basis of this. [ksa]
g	Is able to integrate existing knowledge in a design. [ks]	Is able to formulate new research questions on the basis of a design problem. [ks]
h	Has the skill to take design decisions, and to justify and evaluate these in a systematic manner. [ks]	Idem. [ksa]

k = knowledge
s = skills
a = attitude

4 A scientific approach

A university graduate has a systematic approach characterised by the development and use of theories, models and coherent interpretations, has a critical attitude, and has insight into the nature of science and technology.

k = knowledge
s = skills
a = attitude

	Bachelor	Master
a	Is inquisitive and has an attitude of lifelong learning. [ka]	Is able to identify and take in relevant developments. [ksa]
b	Has a systematic approach characterised by the development and use of theories, models and interpretations. [ksa]	Is able to critically examine existing theories, models or interpretations in the area of his or her graduation subject. [ksa]
c	Has the knowledge and the skill to use, justify and assess as to their value models for research and design (model understood broadly: from mathematical model to scale-model). Is able to adapt models for his or her own use. [ks]	Has great skill in, and affinity with the use, development and validation of models; is able consciously to choose between modelling techniques. [ksa]
d	Has insight into the nature of science and technology (purpose, methods, differences and similarities between scientific fields, nature of laws, theories, explanations, role of the experiment, objectivity etc.). [k]	Idem, and has knowledge of current debates about this. [k]
e	Has insight into the scientific practice (research system, relation with clients, publication system, importance of integrity etc.). [k]	Idem, and has knowledge of current debates about this. [k]
f	Is able to document adequately the results of research and design with a view to contributing to the development of knowledge in the field and beyond. [ksa]	Idem, and is able to publish these results. [ksa]

5 Basic intellectual skills

A university graduate is competent in reasoning, reflecting, and forming a judgment. These are skills which are learned or sharpened in the context of a discipline, and which are generically applicable from then on.

	Bachelor	Master
a	Is able (with supervision) to critically reflect on his or her own thinking, decision making, and acting and to adjust these on the basis of this reflection. [ks]	Idem, independently. [ksa]
b	Is able to reason logically within the field and beyond; both 'why' and 'what-if' reasoning. [ks]	Is able to recognise fallacies. [ks]
c	Is able to recognise modes of reasoning (induction, deduction, analogy etc.) within the field. [ks]	Is able to apply these modes of reasoning. [ksa]
d	Is able to ask adequate questions, and has a critical yet constructive attitude towards analysing and solving simple problems in the field. [ks]	Idem, for more complex (real-life) problems. [ksa]
e	Is able to form a well-reasoned opinion in the case of incomplete or irrelevant data. [ks]	Idem, taking account of the way in which that data came into being. [ks]
f	Is able to take a standpoint with regard to a scientific argument in the field. [ksa]	Idem, and is able to assess this critically as to its value. [ksa]
g	Possesses basic numerical skills, and has an understanding of orders of magnitude. [ks]	Idem. [ksa]

k = knowledge
s = skills
a = attitude

6 Competent in co-operating and communicating

A university graduate has the competence of being able to work with and for others. This requires not only adequate interaction, a sense of responsibility, and leadership, but also good communication with colleagues and non-colleagues. He or she is also able to participate in a scientific or public debate.

k = knowledge
s = skills
a = attitude

	Bachelor	Master
a	Is able to communicate in writing about the results of learning, thinking and decision making with colleagues and non-colleagues. [ks]	Is able to communicate in writing about research and solutions to problems with colleagues, non-colleagues and other involved parties. [ksa]
b	Is able to communicate verbally about the results of learning, thinking and decision making with colleagues and non-colleagues. [ks]	Is able to communicate verbally about research and solutions to problems with colleagues, non-colleagues and other involved parties. [ksa]
c	Idem to above (verbally and in writing), but in a second language. [ks]	idem to above (verbally and in writing), but in a second language. [ksa]
d	Is able to follow debates about both the field and the place of the field in society. [ks]	Is able to debate about both the field and the place of the field in society. [ksa]
e	Is characterised by professional behaviour. This includes: drive, reliability, commitment, accuracy, perseverance and independence. [ksa]	Idem. [ksa]
f	Is able to perform project-based work: is pragmatic and has a sense of responsibility; is able to deal with limited sources; is able to deal with risks; is able to compromise. [ksa]	Idem, for more complex projects. [ksa]
g	Is able to work within an interdisciplinary team. [ks]	Idem, for a team with great disciplinary diversity. [ksa]
h	Has insight into, and is able to deal with, team roles and social dynamics. [ks]	Is able to assume the role of team leader. [ks]

7 Takes account of the temporal and social context

Science and technology are not isolated, and always have a temporal and social context. Beliefs and methods have their origins; decisions have social consequences in time. A university graduate is aware of this, and has the competence to integrate these insights into his or her work.

	Bachelor	Master
a	Understands relevant (internal and external) developments in the history of the fields concerned. This includes the interaction between the internal developments (of ideas) and the external (social) developments. [ks]	Integrates aspects of this in scientific work. [ksa]
b	Is able to analyse and to discuss the social consequences (economical, social, cultural) of new developments in relevant fields with colleagues and non-colleagues. [ks]	Integrates these consequences in scientific work. [ksa]
c	Is able to analyse the consequences of scientific thinking and acting on the environment and sustainable development. [ks]	Integrates these consequences in scientific work. [ksa]
d	Is able to analyse and to discuss the ethical and the normative aspects of the consequences and assumptions of scientific thinking and acting with colleagues and non-colleagues (both in research and in designing). [ks]	Integrates these ethical and normative aspects in scientific work. [ksa]
e	Has an eye for the different roles of professionals in society. [ks]	Chooses a place as a professional in society. [ksa]

k = knowledge
s = skills
a = attitude

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