



EDISON Data Science Framework:

Part 3. Data Science Model Curriculum (MC-DS)

Release 1

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Executive summary

Data Science is an emerging field of science, which requires a multi-disciplinary approach and should be built with a strong link to emerging Big Data and data driven technologies, and consequently needs re-thinking and re-design of both traditional educational models and existing courses. The education and training of Data Scientists currently lacks a commonly accepted, harmonized instructional model that reflects by design the whole lifecycle of data-handling in modern, data driven research and the digital economy.

The presented Data Science Model Curriculum completes the definition of the EDISON Data Science Framework (EDSF) as a foundation for the Data Science profession definition. The EDSF includes the following core components: Data Science Competence Framework (CF-DS), Data Science Body of Knowledge (DS-BoK), Data Science Model Curriculum (MC-DS), and Data Science Professional profiles definition (DSP profiles).

The MC-DS is built based on CF-DS and DS-BoK, where Learning Outcomes are defined based on CF-DS competences and Learning Units are mapped to Knowledge Units in DS-BoK. In its own turn, Learning Units are defined based on the ACM Classification of Computer Science (CCS2012) and reflect typical courses naming used by universities in their current programmes. The suggested Learning Units are assigned suggested labels, marking their relevance to the core Data Science knowledge areas in a form of Tier 1, Tier 2, or Elective courses. Further MC-DS refinement will be done based on consultation with the universities community and experts both in Data Science and scientific or industry domains.

The proposed MC-DS intends to provide guidance to universities and training organisations in the construction of Data Science programmes and individual courses selection that are balanced according to requirements elicited from the research and industry domains. MC-DS can be used for assessment and improvement of existing Data Science programmes with respect to the knowledge areas and competence groups that are associated with specific professional profiles. When coupled with individual or group competence benchmarking, MC-DS can also be used for building individual training curricula and professional (self/up) skilling for effective career management.

Further work will be required to develop consistent MC-DS that can be used by academic community and professional training community. The proposed initial version will be used to initiate community discussion and solicit contribution from the subject matter experts and practitioners. The MC-DS will be presented to the EDISON Liaison Groups of experts for feedback and will undergo wide community discussion via EDISON community forum and by presentation at community oriented workshops and conferences.

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1 Introduction

Data Science is an emerging field of science, which requires a multi-disciplinary approach and should be built with the strong link to Big Data and data driven technologies that created transformational effect to all research and industry domains, and consequently require re-thinking and re-design of both traditional educational models and existing courses. However, at present time most of the existing university curricula and training programs are built based on available courses and cover limited set of academic subject related to a full Data Science Body of Knowledge covering only limited set of knowledge areas and professional profiles as defined in the project. This potentially may create gaps in knowledge and competences of the future Data Scientist graduates for their smooth integration in the real working environment (both in industry and academia).

The presented in this deliverable the Data Science Model Curriculum completes the foundational EDISON Data Science Framework that includes Data Science Competence Framework (CF-DS or Competence Framework), Data Science Body of Knowledge (DS-BoK or Body of Knowledge), Data Science Model Curriculum (MC-DS or Model Curriculum), and Data Science Professional profiles definition and taxonomy (DSP or Professional profiles). More details are provided in chapter 2.

The proposed Data Science Model Curriculum will reuse the best practices in curriculum design and new educational model to facilitate the students learning as well as existing staff professional training and re-skilling for data related technologies. Building on insights gathered through thorough analyses of existing Data Science programmes (performed in WP2 Task 2.2 and reported in Deliverable D2.2 [3]) and the requirements of targeted educational stakeholders, the Model Curriculum reflects by design the whole data handling/processing lifecycle and organizational or structural processes (such as scientific methods and data driven research cycle, Business Process Management cycle as defined in Deliverable D2.1 Section 2.7 [2]).

The definition of the MC-DS can be used as instrumental in defining recommended training for Data Science professional certification programs. From the practical perspective, the Model Curriculum represents a tool for

- i) supporting the development of new Data Science programmes (including appraisal/selection of appropriate units/modules) tailored according to proficiency levels required to address competences required for identified Data Science Professional profiles, and
- ii) assessing the coverage of existing Data Science programmes, facilitating the elicitation of potential gaps w.r.t. to specific competence groups and knowledge areas implied by targeted professional profiles.

Hence, the Model Curriculum helps matching the supply-side and demand-side requirements for Data Science education. The formal definition of the Data Science Model Curriculum will create a basis for Data Science educational and training programmes compatibility and consequently Data Science related competences and skills transferability.

Further work will be required to develop consistent MC-DS that can be used by academic community and professional training community. The proposed initial version will be used to initiate community discussion and solicit contribution from the subject matter experts and practitioners. The MC-DS will be presented to the EDISON Liaison Groups of experts for feedback and will undergo wide community discussion via EDISON community forum and by presentation at community oriented workshops and conferences.

The presented document has the following structure. Section 2 provides an overview of the EDISON Data Science framework and related project activities that support the framework components development and pilot implementation. Section 3 provides overview of existing BoKs related to Data Science knowledge areas. Section 3 also includes other important components for the DS-BoK definition such as data lifecycle management models, research methods, and business process management models. Section 4 briefly discusses the DS-BoK structure that is defined in another project document [2]. Section 5 describes the proposed approach to building MC-DS and provides initial definition of the MC-DS. Section 6 provides summary of the achieved results and section 7 suggests a number of questions for discussion to collect community feedback and experts opinion.

Appendices to this document contain important supplementary information: examples of reviewed existing curricula that represent best practices for Data Science curricula and education; taxonomy of the Data Science knowledge areas and scientific disciplines extracted as a subset of the ACM CCS (2012) classification; and a short summary of the proposed CF-DS that includes identified competence groups and skills, required technical knowledge of relevant Big Data platforms, analytics and data management tools, and programming languages.

2 EDISON Data Science Framework

The EDISON vision for building the Data Science profession will be enabled through the creation of a comprehensive framework for Data Science education and training that includes such components as Data Science Competence Framework (CF-DS), Data Science Body of Knowledge (DS-BoK) and Data Science Model Curriculum (MC-DS).

Figure 1 below illustrates the main components of the EDISON Data Science Framework (EDSF) and their inter-relations that provides conceptual basis for the development of the Data Science profession:

- CF-DS – Data Science Competence Framework [4]
- DS-BoK – Data Science Body of Knowledge [5]
- MC-DS – Data Science Model Curriculum [6]
- DSP - Data Science Professional profiles and occupations taxonomy [7]
- Data Science Taxonomy and Scientific Disciplines Classification (including Vocabulary)

The proposed framework provides a basis for other components of the Data Science professional ecosystem:

- EDISON Online Education Environment (EOEE)
- Education and Training Marketplace and Directory
- Data Science Community Portal (CP) that also includes tools for individual competences benchmarking and personalized educational path building
- Certification Framework for core Data Science competences and professional profiles

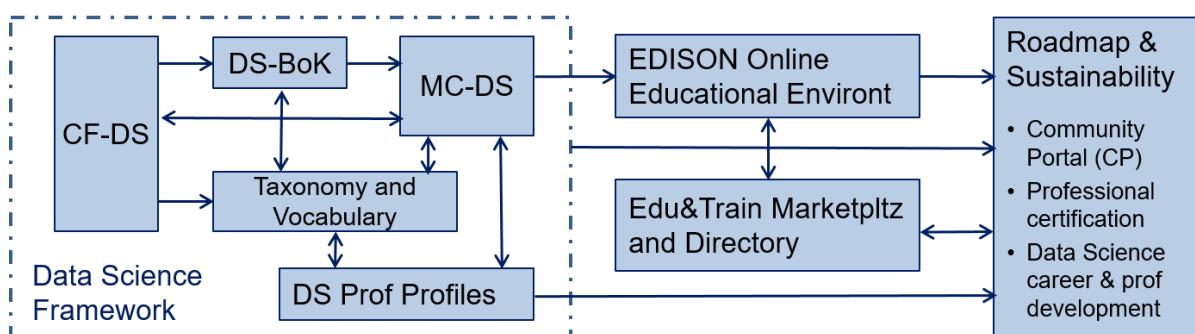


Figure 1 EDISON Data Science Framework components.

The CF-DS includes common competences required for successful work of Data Scientists in different work environments in industry and in research and through the whole career path. The future CF-DS development will include coverage of the domain specific competences and skills and will involve domain and subject matter experts.

The DS-BoK defines the Knowledge Areas (KA) for building Data Science curricula that are required to support required Data Science competences. DS-BoK is organised by Knowledge Area Groups (KAG) that correspond to the CF-DS competence groups. DS-BoK incorporates best practices in Computer Science and domain specific BoK's and includes KAs defined based on the Classification Computer Science (CCS2012), components taken from other BoKs and proposed new KAs to incorporate new technologies used in Data Science and their recent developments.

The MC-DS is built based on CF-DS and DS-BoK where Learning Outcomes are defined based on CF-DS competences and Learning Units are mapped to Knowledge Units in DS-BoK. Three mastery (or proficiency) levels are defined for each Learning Outcome to allow for flexible curricula development and profiling for different Data Science professional profiles.

The DSP profiles and Data Science occupations taxonomy are defined based on and as an extension to the European Skills, Competences, Qualifications and Occupations (ESCO). DSP profiles definition will create an important instrument to define effective organisational structures and corresponding roles. DSP can also be

used for building individual career path and corresponding competences and skills transferability between organisations and economy sectors.

The Data Science Taxonomy and Scientific Disciplines Classification will serve to maintain consistency between four core components of EDSF. To ensure easy navigation and mapping between the EDSF components, all attributes and properties are enumerated: competences in CF-DS, KAGs and KAs in DS-BoK, LOs and LUs in MC-DS, professional profiles in DSP.

The EDISON Data Science professional ecosystem illustrated in Figure 1 uses core EDSF components to shape and profile the offered services and ensure the EDISON project sustainability. In particular, CF-DS and DS-BoK are used for individual competences and knowledge benchmarking and they are instrumental for constructing personalised learning path and professional (up/re-) skilling based on MC-DS.

3 Overview of Best Practices in Curricula Design

This section provides background information and best practices in building effective professional curricula for specific domains of knowledge, target groups and purposes. The reviewed selected learning model and curricula design models are used to develop the EDISON approach that is targeted to provide quality education and training for specific groups of Data Science related professions to acquire necessary competences and skills.

The following curricula and Body of Knowledge have been reviewed to identify best practices and components to be used for the initial definition of the MC-DS structure and content:

- ACM Computer Science Curriculum and Body of Knowledge (ACM CS2013 and CS-BoK) [8]
- Information Technology Competency Model of Learning Outcome ACM CCECC2014 [9]
- ICT professional Body of Knowledge and ICT leadership curriculum (ICT-BoK) [10]

Other relevant BoKs that were used in defining the DS-BoK are reviewed in the corresponding DS-BoK document [5], their components are used in the DS-BoK presented in section 4:

- Data Management Body of Knowledge (DM-BoK) by Data Management Association International (DAMAI) [11]
- Software Engineering Body of Knowledge (SWEBOK) [12]
- Business Analytics Body of Knowledge (BABOK) [13]
- Project Management Professional Body of knowledge (PM-BoK) [14]

It is important to mention that due to complex nature of the Data Science profession consisting of few quite different knowledge areas, the MC-DS definition will require combination of different BoKs and different approaches to curriculum definition, different subject domains and learning models. The final curriculum definition will depend on local conditions defined by demand side, available teaching staff and expertise, and available educational base and infrastructure.

3.1 Learning models and curriculum design approaches

To define consistently the MC-DS, we need to understand the commonly accepted approaches to defining education and training programmes and put them in the context of the European education system and policies, also consider alignment with the international practices. Two approaches to education and training are followed in practice, the traditional approach which is based on defining the time students have to spend learning a given topics or concept like the European Credit Transfer and Accumulation System (ECTS) [15] or Carnegie unit credit hour [16]. The former is also known as competence-based education or outcomes-based learning (OBE), it is focusing on the outcome assessing whether students have mastered the given competences, namely the skills, abilities, and knowledge. There is no specified style of teaching or assessment in OBE; instead classes, opportunities, and assessments should all help students achieve the specified outcomes. In 2012, the EC has called for a rethinking of education towards OBE approach. The motivation for such a rethinking is to ensure that education is more relevant to the needs of students and the labour market, assessment methods need to be adapted and modernised. Not like the traditional BoK which is defined in term of Knowledge Areas (KA), in OBE the BoK and curriculum are defined in term of the core learning outcomes which are grouped into technical competence areas and workplace skills.

3.1.1 Bloom's Taxonomy

Bloom's taxonomy [17] provides a conceptual framework to organize levels of learning of a topic or subject, and assigns action verbs to each level that help to understand activities related with particular level of learning. **Error! Reference source not found.** Illustrates (see **Figure 2**). For instance, students start at the *knowledge* level when they can *name* and *identify* relevant technologies. The further move to *comprehension* level when they can *explain* how technologies work. They can then move to *application* level when they can *choose* right technology to *solve* a problem. Further they can progress to *analysis*, *synthesis*, and finally *evaluation* levels.

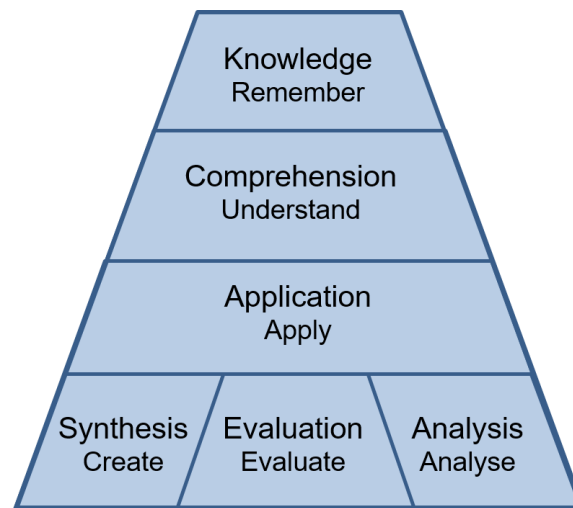


Figure 2 Simple Bloom's taxonomy: Learning levels and action verbs.

Below example shows typical attributes of the different levels of learning and example questions to test these levels.

Knowledge

Exhibit memory of previously learned materials by recalling facts, terms, basic concepts and answers

Knowledge of specifics - terminology, specific facts

Knowledge of ways and means of dealing with specifics - conventions, trends and sequences, classifications and categories, criteria, methodology

Knowledge of the universals and abstractions in a field - principles and generalizations, theories and structures

Questions like: What are the main benefits of implementing Big Data and data analytics methods for organisation?

Comprehension

Demonstrate understanding of facts and ideas by organizing, comparing, translating, interpreting, describing, and stating the main ideas

Translation, Interpretation, Extrapolation

Questions like: Compare the business and operational models of private clouds and hybrid clouds.

Application

Using new knowledge. Solve problems in new situations by applying acquired knowledge, facts, techniques and rules in a different way

Questions like: What data analytics methods should be applied for specific data types analysis or for specific business processes and activities Which Big Data services architecture is best suited for medium size research organisation or company, and why?

Analysis

Examine and break information into parts by identifying motives or causes. Make inferences and find evidence to support generalizations

Analysis of elements, relationships, organizational principles

Questions like: What data analytics methods and services are required to support typical business processes of a web trading company? Give suggestions how these services can be implemented with the selected data analytics platform, including on-premises or outsourced to cloud. Provide references to support your statements.

Synthesis

Compile information together in a different way by combining elements in a new pattern or proposing alternative solutions

Questions like: Describe the main steps and tasks for implementing data analytics and data management services for an example company or research organisation? What services and data analytics can be moved to clouds and which will remain at the enterprise premises and run by company's personnel?

Present and defend opinions by making judgments about information, validity of ideas or quality of work based on a set of criteria

Questions like: Do you think that implementing Agile Data Driven Enterprise model creates benefits for enterprises, short term and long term?

BLOOM'S TAXONOMY - LEARNING IN ACTION

The diagram is a circular flower-like structure with six petals, each representing a level of Bloom's Taxonomy. The center is a green circle with the word 'comprehension' and the number '2'. The petals are numbered 1 through 6, with corresponding verbs and cognitive processes. The outer ring lists various media and activities associated with each level.

Level	Verb	Cognitive Process	Media/Activities
1	select	knowledge	events, videos, people, recordings, filmstrips
2	match, restate, paraphrase, rewrite, give examples, express, illustrate	comprehension	radio, newspapers, magazines, television, text, reading, film, recording, drama, cartoon, story, speech, photograph, diagram, own statement
3	organize, generalize, prepare, choose, sketch, apply, draw, paint	application	list, drama, painting, sculpture, jewelry, poetry
4	differentiate, subdivide, infer, survey, select, prioritize	analysis	illustration, solution, question, outline, map, project, forecast, diagram
5	compose, originate, hypothesize, develop, design, combine	synthesis	word, defined, statement, identify, conclusion, checked, questionnaire, argument, propaganda
6	evaluate	evaluation	survey, graph, syllogism, breakdown, report

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3.1.2 Constructive Alignment and Problem-based Learning

The traditional and still usual approach in science and engineering education is based on a behaviorist or objectivist epistemology, in which the student is passively imparted with knowledge by the teacher. Student's participation in the learning process is limited to memorizing schemes given by the instructor, which are assessed through instruments such as examinations and quizzes that measure the degree of conformance to a norm instead of actual competences [19]. In contrast, a constructivist epistemology puts the student in the center of the learning process as an active participant in constructing knowledge [20].

Problem Based Learning (PBL) [21, 22] is an alternative approach to instruction based on providing student with a non-trivial problem to solve, and guidance in obtaining the necessary competencies. PBL is underlined by a constructivist epistemology that emphasizes active student participation in the construction of their knowledge from learning activities and motivating them through careful alignment of evaluation activities, leading to a concept called Constructive Alignment described by Biggs [23]. Ben-Ari [24] describes the applicability of constructivism to computer science education. Despite certain differences in epistemology between computer science and other sciences, constructivism is a useful approach to computer science education.

From the perspective of a whole education program, constructive alignment and problem-based learning can be implemented in a form of project-based learning. In such a model regular classes provide students with competences related to specific knowledge areas, while additional project classes allow to establish a link between these competences. In addition, project classes provide an opportunity to reach higher levels of learning. An example of such approach on an institutional scale is University of Aalborg [25].

These education concepts provide guidance for further definition of Learning Outcomes and finally Model Curricula, and can be used for the existing programmes evaluation.

3.1.3 Competence Based Learning Model

Competency Based Learning (CBL) or Competence Based Education (CBE) also known as outcomes based learning uses a different from the traditional education approach. Instead of focusing on how much time students spend learning a particular topic or concept (Carnegie unit credit hour, so called "sit time"), the CBL assesses whether students have mastered the given competencies, namely the knowledge, skills, and abilities [9]. The learner (student or trainee) is evaluated on the specified (group of) competences, and only after mastering them they can move on to others. The CBL is also associated with more flexible study model for already working learners or those who undergo professional re-skilling or want to train for a new profession based on their existing experience, competences and skills. In this case, they can skip learning modules entirely if they can demonstrate require competences through the assessment system or formal testing.

The CBL can also allow the students to learn in their own pace, practicing necessary skills as much as they need to achieve necessary mastery level. It works naturally with both individual self-study and with teacher or instructor supervised/facilitated study, so well suited for online and remote education, and in particular for post-graduate education. CBL is also associated with such educational technologies and models as MOOCs, flipped classrooms, learning analytics, and others targeting growing needs of life-long learning and self-re-skilling dictated by current fast technologies development. The CBL programmes should offer the following features [26]:

- Self-pacing
- Modularization
- Effective assessments
- Intentional and explicit learning objectives shared with the student,
- Anytime/anywhere access to learning objects and resources,
- Personalized, adaptive or differentiated instruction
- Learner supports through instructional advising or coaching.

Although there are many universities CBL/CBE model, its practical implementation may create problems in some universities. Paper [27] by formulates the following principles that would allow integrating CBE into existing campus structures:

- The degree reflects robust and valid competencies.
- Students are able to learn at a variable pace and are supported in their learning.
- Effective learning resources are available any time and are reusable.
- Assessments are secure and reliable.

It is apparent that CBL is well suited for professional education and training of one of the EDISON target groups the self-made or practicing Data Scientists. It is admitted [26] that the CBL was actually created to address needs of non-traditional students who cannot devote their full time to traditional academic study as well as effective model for companies to provide (re/up) skilling their staff.

3.2 ACM Computer Science Curriculum (CS2013) and Body of Knowledge (CS-BoK)

In the ACM-CS2013-final report [8] the Body of Knowledge is defined as a specification of the content to be covered in a curriculum as an implementation. The ACM-BoK describes and structures the knowledge areas needed to define a curriculum in Computer Science, it includes 18 Knowledge Areas (where 6 KAs are newly introduced in ACM CS2013):

AL - Algorithms and Complexity
 AR - Architecture and Organization
 CN - Computational Science
 DS - Discrete Structures
 GV - Graphics and Visualization
 HCI - Human-Computer Interaction
 IAS - Information Assurance and Security (new)
 IM - Information Management
 IS - Intelligent Systems
 NC - Networking and Communications (new)
 OS - Operating Systems
 PBD - Platform-based Development (new)
 PD - Parallel and Distributed Computing (new)
 PL - Programming Languages
 SDF - Software Development Fundamentals (new)
 SE - Software Engineering
 SF - Systems Fundamentals (new)
 SP - Social Issues and Professional Practice

Knowledge areas should not directly match a particular course in a curriculum (this practice is strongly discouraged in the ACM report), often courses address topics from multiple knowledge areas. The ACM-CS2013-final report distinguishes between two types of topics: Core topics subdivided into “Tier-1” (that are mandatory for each curriculum) and “Tier-2” (that are expected to be covered at 90-100% with minimum advised 80%), and elective topics. The ACM classification suggests that a curriculum should include all topics in Tier-1 and all or almost the topics in Tier 2. Tier 1 and Tier 2 topics are defined differently for different programmes and specialisations. To be complete, a curriculum should cover in addition to the topics of Core Tier 1 and 2 a significant amount of elective material. The reason for such a hierarchical approach to the structure of the Body of Knowledge is a useful way to group related information, not as a structure for organizing material into courses.

The ACM Curriculum for computing Education in Community Colleges [8] defines a BoK for IT outcome-based learning/education which identifies 6 technical competency areas and 5 work-place skills. While the technical areas are specific to IT competences and specify a set of demonstrable abilities of graduates to perform some specific functions, the so called work-place skills describe the ability the student/trainee to:

- (1) function effectively as a member of a diverse team,
- (2) read and interpret technical information,
- (3) engage in continuous learning,
- (4) professional, legal, and ethical behavior, and
- (5) demonstrate business awareness and workplace effectiveness

The ACM steering committee agrees on set principles to guide the development of CS2013 model curriculum. These principles aim at providing students with necessary flexibility to work across disciplines and prepare the graduates for a variety of disciplines. Following is the summary of the most important principles:

- (1) CS2013 should provide guidance for the expected level of mastery of topics by the graduate
- (2) CS2013 should provide realistic, adoptable recommendations that provide guidance and flexibility allowing curricula designs that are innovative and track recent developments in the field
- (3) Size of the essential knowledge must be manageable
- (4) Computer science curricula should prepare graduates to succeed in a rapid changing area
- (5) CS2013 should identify the fundamental skills and knowledge that all computer Science graduate should possess while providing the greatest flexibility in selecting topics
- (6) CS2013 should provide a great flexibility in organizing topics into courses and curricula.

Through these principles ACM provides graduate with fundamental knowledge in the areas described in the ACM-BoK and a style of thinking and problem solving. The latter is achieved through defining the expected characteristics of computer science graduate namely:

- Technical understanding of computer science
- Familiarity with common themes and principals
- Appreciation of interplay between theory and practice
- System-level perspective
- Problem solving skills
- Project experience
- Commitment to life-long learning
- Commitment to professional responsibility
- Communication and organization skills
- Appreciation of domain specific knowledge

ACM follow a simple straight forward approach to design the ACM Model Curriculum. It starts from the CS2013 based CS-BoK which is structured into Knowledge areas (KA), organized in topical themes rather than by courses boundary. Each KA is further organized into a set of Knowledge Units (KU). In the final step each KU lists a set of topics and learning outcomes (LO). The LO are associated with a level of mastery derived from the Bloom taxonomy (familiarity, usage, and assessment).

The CS-BoK uses ACM Computing Classification System (CCS2012) for defining BoK topics and academic subject. Necessary extensions/KAs related to identified Data Science competence groups are provided as CCS2012 extension points (see Appendix B).

3.3 ACM/IEEE-CS Curricula Guidelines and Competency Model for Information Technologies

The ACM Committee for Computing Education in Community Colleges (CCECC) and its partner professional societies (in particular, IEEE Computer Society) have jointly produced curricular recommendations and guidelines for baccalaureate computing programs, known collectively as the ACM Computing Curricula series. One of these guidelines is the Curriculum Guidelines for Undergraduate Degree Programs in Information Technology (IT2008) and its later published companion document ACM Competency Model of Core Learning Outcomes and Assessment for Associate-Degree Curriculum in Information Technology (IT2014) [9]. The guidelines use the competence-based learning model that focuses on the extent that students learn given competencies (knowledge, skills, qualifications), instead of focusing on so called „seat time“, commonly expressed by credit points. The proposed competency model for constructing Information Technology curricula is based on defining measurable learning outcomes. The CCECC identified the Body of Knowledge as a set of fifty student learning outcomes that span the first three levels of Bloom’s Revised Taxonomy (see above), and each outcome is accompanied by a three-tier assessment rubric that provides additional clarity and a measureable evaluation metric [9].

3.4 ICT professional Body of knowledge and new curricula for e-Leadership skills

The ICT-BoK [10] is an effort promoted by the European Commission, under the eSkills initiative (<http://eskills4jobs.ec.europa.eu/>) to define and organise the core knowledge of the ICT discipline. In order to foster the growth of digital jobs in Europe and to improve ICT Professionalism a study has been conducted to provide the basis of a “Framework for ICT professionalism” (<http://ictprof.eu/>). This framework consists of four building blocks (also called pillars) which are also found in other professions:

- i) body of knowledge (BoK);
- ii) competence framework;
- iii) education and training resources; and
- iv) code of professional ethics.

A competence framework already exists and consists in the e-Competence Framework (now in its version 3.0 and promoted by CEN). However, an ICT Body of Knowledge that provides the basis for a common understanding of the foundational knowledge an ICT professional should possess, is not yet available.

The ICT-BoK is suggested to be structured in 5 *Process Groups*, defining the various phases of the project development or organisational workflow: *Initiating, Planning, Executing, Monitoring and Controlling, Closing*.

The ICT-BoK aims at informing about the level of knowledge required to enter the ICT profession and acts as the first point of reference for anyone interested in working in ICT. Even if the ICT-BoK does not refer to Data Science competences explicitly the identified ICT processes can be applied to data management processes both in industry and academia in the context of well-defined and structured projects.

Further ICT BoK was focused on developing the new curricula for e leadership skills in Europe. (refer to the original report [3] for details).

4 Data Science Model Curriculum

This section presents the first definition of the EDISON Data Science Model Curriculum that is primarily based on mapping Learning Units that may represent academic courses and training modules that are mapped to DS-BoK and to Learning Outcomes as defined below.

The proposed MC-DS can be used for defining individual curricula for specific Data Science professional profile or customized individual curricula for practitioners that want to obtain a Data Science qualification or certification. The example of applying competence based approach to selecting a set of Learning Units for different DSP profiles is given in Chapter5. Developing a tool for customizing training and/or education programme for individual trainees or students is a subject of the Task 3.4 activity.

4.1 MC-DS Design approach

In general, a Model Curriculum can be regarded as a blueprint that can be used by educators and trainers to develop curricula at various educational institutions. There are several concepts that can guide the development of a curriculum like: Alignment and Coherence, Scope, Sequence, Continuity, and Integration [30]. These 5 basic concepts help to develop a logically consistent curriculum which components (courses, and learning units) complement each other and are ordered in such a way that it form a continuous, logical, and progressive learning path. There are several common frameworks used to develop model curricula some are subject or discipline centric while others are organized around concept and skills that are revised as we progress across the curriculum. In practice, model curricula should define either the time students have to spend learning given topics (usually using credit units) or the outcome assessing whether students have mastered the given competences (knowledge, abilities and skills). The latter approach is known as Competence-Based Education (CBE) or Outcomes-Based Learning (OBL). In this case, well-defined learning outcomes are specified for all academic activities or classes are specified, and students' progress is assessed against those learning outcomes.

The Model Curriculum are organized as core and elective topics, following the ACM definition [8]. Core topics are required to every Data Science program while Elective topics aim to cover in depth the knowledge on a specific area of data science. The last step identifies the Learning outcomes associated to each core or elective topic.

The EDISON approach to defining the Data Science Model Curriculum follows a competence-base education model and can be summarized in the following steps:

1. For each enumerated competence from CF-DS, define Learning Outcome according to knowledge or mastery level (defined as Familiarity, Usage, Assessment for current MC-DS version)
2. Each Knowledge Area Group of DS-BoK (that includes both KAGs from existing BoKs and those defined based on the ACM Classification Computer Science CCS2012 is mapped to existing academic subject classification groups that is primarily based on ACM CS2012 complemented with the domain or technology specific classifications such as BABOK, ACM-BOK, DAMA-BOK, PM-BOK, and others to be defined by subject matter experts.
3. For each KAG or Knowledge Unit, specify related Learning Units defined according to academic subject classification or following current practices by universities
4. For each Learning Unit, assign/suggest its category as core/mandatory (Tier1 or Tier 2), elective or prerequisite
5. For both Core or Elective, define a list of Learning Outcomes

4.2 Mastery levels and Learning Outcomes

In this section, we compare mastery levels as used in the European Qualifications Framework (EQF) [28], The European e-Competence Framework (e-CFv3.0) [29], ACM/IEEE guidelines for Computer Science curriculum [8] and Bloom's taxonomy [17]. It leads to the definition of mastery levels (also called proficiency levels in e-CF) necessary to define Learning Outcomes in MC-DS. The e-CFv3.0 uses EQF for defining the proficiency level of knowledge and skills related to specific competences.

The European Qualification Framework (EQF) [28] defines eight levels of knowledge achieved through stages of education. Level 6 is considered to be achieved through a bachelor degree, level 7 through a master's degree and level 8 through a PhD degree. Levels 3-8 are mapped to 5 levels in e-CF dimension 3.

EQF descriptions provide reference both to actual levels of knowledge, but also to additional skills related to knowledge application, analysis, synthesis and evaluation. It is quite similar to Bloom's approach. At the same time, levels in EQF do not only correspond to higher levels of conceptualization, but also to more specialized knowledge, experience and interpersonal skills related to people management, and professional integrity and responsibility. e-CFv3.0 adds to its description of typical tasks regarding their complexity and autonomy. Therefore, higher levels of EQF and e-CFv3.0 should not just be seen directly as the same higher levels in Bloom. At the same time, higher levels in Bloom's taxonomy are necessary to move up in e-CFv3.0 and EQF.

EQF has 8 levels, e-CFv3.0 has 5 levels and Bloom's Taxonomy has 6 levels. Designing LOs of whole programs is a balance between precision and avoiding micromanagement of further definition of courses, especially when designing a guideline for programs instead of a specific program. It might be useful to limit the amount of levels on which LOs are considered. Such an approach is used in ACM/IEEE Computer Science and Information Technology curricula guidelines. Information Technology guidelines [9] define the three levels as: emerging, developed and highly developed. Computer Science guidelines [8] define the three levels as: familiarity, usage, and assessment. Bloom's taxonomy defines the six levels: knowledge, comprehension, application, analysis, synthesis and evaluation.

The three levels as used in ACM/IEEE Computer Science guidelines are of particular importance because significant parts of a related ACM/IEEE taxonomy and BoK is used in the definition of CF-DS and BoK-DS in EDISON. The verb usage is not fully consistent with the original Bloom's taxonomy [17] or revised version, which is acknowledged in the document.

The comparison of the mastery levels definition used in EQF, e-CFv3.0, ACM/IEEE guidelines for Computer Science curriculum and Bloom's taxonomy is provided in Appendix A. Mastery levels.

While not required in undergraduate curricula, the holistic definition covering all EQF, e-CF levels, requires also full coverage of levels in Bloom's taxonomy. At the same time, limitation to 3 levels should be maintained to preserve simplicity and compatibility. For the proposed MC-DS we will use the following three levels: familiarity as understood by knowledge and comprehension in Bloom's taxonomy, usage as understood by application and analysis in Bloom's taxonomy, creation as understood by synthesis and evaluation in Bloom's taxonomy. We present the three levels again in this document for reference in **Table 1**. Details on the relation to EQF and e-CF levels can be found in Appendix A. Mastery levels. Action verbs were defined based on the original and revised Bloom's taxonomy with adjustments tailored to Data Science curricula.

Table 1 Knowledge levels for learning outcomes in Data Science model curricula (MC-DS)

Level	Action Verbs
Familiarity	Choose, Classify, Collect, Compare, Configure, Contrast, Define, Demonstrate, Describe, Execute, Explain, Find, Identify, Illustrate, Label, List, Match, Name, Omit, Operate, Outline, Recall, Rephrase, Show, Summarize, Tell, Translate
Usage	Apply, Analyze, Build, Construct, Develop, Examine, Experiment with, Identify, Infer, Inspect, Model, Motivate, Organize, Select, Simplify, Solve, Survey, Test for, Visualize
Assessment	Adapt, Assess, Change, Combine, Compile, Compose, Conclude, Criticize, Create, Decide, Deduct, Defend, Design, Discuss, Determine, Disprove, Evaluate, Imagine, Improve, Influence, Invent, Judge, Justify, Optimize, Plan, Predict, Prioritize, Prove, Rate, Recommend, Solve

4.3 Learning Outcomes definition based on CF-DS

Table 2 presented below provides a template and examples for defining the Learning Outcomes related to enumerated CF-DS competences and different knowledge/proficiency levels defined based on Bloom's Taxonomy. The table contains the general Learning Outcomes defined after CF-DS competences that are in most cases split into 3 knowledge levels and use specific verbs that reflect necessary comprehension or mastery level.

Table 2 Learning outcomes defined for CF-DS competences and different mastery/proficiency levels

LO ID	Data Science Competence	LO by Knowledge levels (compliant to ACM CSC 2013) and key verbs		
		Familiarity	Usage	Assessment
		Choose, Classify, Collect, Compare, Configure, Contrast, Define, Demonstrate, Describe, Execute, Explain, Find, Identify, Illustrate, Label, List, Match, Name, Omit, Operate, Outline, Recall, Rephrase, Show, Summarize, Tell, Translate	Apply, Analyze, Build, Construct, Develop, Examine, Experiment with, Identify, Infer, Inspect, Model, Motivate, Organize, Select, Simplify, Solve, Survey, Test for, Visualize	Adapt, Assess, Change, Combine, Compile, Compose, Conclude, Criticize, Create, Decide, Deduct, Defend, Design, Discuss, Determine, Disprove, Evaluate, Imagine, Improve, Influence, Invent, Judge, Justify, Optimize, Plan, Predict, Prioritize, Prove, Rate, Recommend, Solve
Data Science Data Analytics				
LO1-DA	DSDA-DA - Use appropriate statistical techniques and predictive analytics on available data to deliver insights and discover new relations.	Choose appropriate existing analytical method and operate existing tools to do specified data analysis. Present data in the required form.	Develop data analysis application for specific data sets and tasks or processes. Identify necessary methods and use them in combination if necessary. Identify relations and provide consistent reports and visualizations.	Create formal model for the specific organizational tasks and processes and use it to discover hidden relations, propose optimization and improvements. Develop new models and methods if necessary. Recommend and influence organizational improvement based on continuous data analysis.
LO1.01	DSDA01 - Use predictive analytics to analyze big data and discover new relations.	Choose and execute existing predictive analytics tools.	Identify existing requirements and develop predictive analysis tools.	Design and evaluate predictive analysis tools to discover new relations.
LO1.02	DSDA02 - Use appropriate statistical techniques on available data to deliver insights.	Choose and execute standard methods from existing statistical libraries to provide overview.	Select most appropriate statistical techniques and model available data to deliver insights.	Assess and optimize organization processes using statistical techniques.
LO1.03	DSDA03 - Develop specialized analytics to enable agile decision making.	Define data elements necessary to develop specified data analytics.	Develop specialized analytics to enable decision-making.	Design specialized analytics to improve decision-making.
LO1.04	DSDA04 - Research and analyze complex data sets, combine different sources and types of data to improve analysis.	Operate tools for complex data handling.	Analyze available data sources and develop tool that work with complex datasets.	Assess, adapt, and combine data sources to improve analytics
LO1.05	DSDA05 - Use different data analytics platforms to process complex data.	Name and operate major data analytic platforms.	Examine existing platforms and select most appropriate	Evaluate and recommend data analytics platforms w.r.t.

			platform w.r.t. technical specification.	organizational strategy.
LO1.06	DSDA06 - Visualise complex and variable data.	Choose and execute standard visualization.	Build visualizations for complex and variable data.	Create and optimize visualizations to influence executive decisions.
Data Science Data Management				
LO2-DM	DSDM-DM - Develop and implement data management strategy for data collection, storage, preservation, and availability for further processing.	Execute data strategy in a form of Data Management Plan and illustrate how available software can help to promote data quality and accessibility.	Develop components of data strategy and methods that improve quality, accessibility and publications of data.	Create Data Management Plan aligned with the organizational needs, evaluate IPR and ethical issues.
LO2.01	DSDM01 - Develop and implement data strategy, in particular, in a form of Data Management Plan (DMP).	Explain and execute data strategy in a form of Data Management Plan.	Develop components of data strategy in a form of Data Management Plan.	Assess various data strategies and create strategy, in a form of Data Management Plan, aligned with organizational needs.
LO2.02	DSDM02 - Develop and implement relevant data models, including metadata.	Operate data models including metadata.	Experiment with data models and model relevant metadata.	Evaluate and design data models, including metadata.
LO2.03	DSDM03 - Collect and integrate different data source and provide them for further analysis.	Collect different data sources.	Survey and visualize connection between different data sources.	Compose different data sources to enable further analysis.
LO2.04	DSDM04 - Develop and maintain a historical data repository of analysis results (data provenance).	Operate a historical data repository.	Construct a historical data repository.	Improve or design a historical data repository.
LO2.05	DSDM05 - Ensure data quality, accessibility, publications (data curation).	Illustrate how available software can help to promote data quality, accessibility and publications.	Develop methods that improve quality, accessibility and publications of data.	Improve quality, accessibility and publications of data.
LO2.06	DSDM06 - Manage IPR and ethical issues in data management.	Configure data management software to manage IPR and ethical issues.	Identify IPR and ethical issues in data repository.	Evaluate IPR and ethical issues in data repository.
Data Science Engineering				
LO3-ENG	DS-ENG - Use engineering principles to research, design, develop and implement new instruments and applications for data collection, analysis and management.	Identify and operate instruments and applications for data collection, analysis and management	Model problems and develop new instruments and applications for data collection, analysis and management following established engineering principles.	Evaluate instruments and applications to optimize data collection, analysis and management.
LO3.01	DSENG01 - Use engineering principles to research, design, prototype data analytics applications, or develop structures, instruments, machines, experiments, processes, systems.	Choose potential technologies to develop, structure, instrument, machines, experiments, processes, and systems.	Model data analytics application to better develop suitable instruments, machines, experiments, processes, and systems.	Create innovative solution to research and design data analytics
LO3.02	DSENG02 - Develop and apply computational solutions to domain related problems using wide range of data	Name computational solution and identify potential data analytics platform	Apply existing computational solutions to data analytic platform.	Adapt and optimize existing computational solutions to better fit to a given data analytics

	analytics platforms.			platform.
LO3.03	DSENG03 - Develops specialized data analysis tools to support executive decision making.	Identify a set of potential data analytics tools to fit specification.	Survey various specialized data analytics tools and identify the best option.	Evaluate and recommend optimal data analytics tools to influence decision making.
LO3.04	DSENG04 - Design, build, operate database technologies.	Find possible database solutions including both relational and non-relational databases.	Model the problem to apply database technology.	Predict the difference in term of performance between relational and non-relational databases and recommend a solution.
LO3.05	DSENG05 - Develop solutions for secure and reliable data access.	Identify security issues related to reliable data access.	Analyze security threats and solve them using known techniques.	Evaluate security threats and recommend adequate solutions.
LO3.06	DSENG06 - Prototype new data analytics applications.	Define technical requirements for new data analytics application for a given high-level design.	Apply existing techniques to develop new data analytics applications.	Combine several techniques and optimize them to design new data analytic applications.
Data Science Research Methods				
LO4-RM	DS-RM - Create new understandings and capabilities by using the scientific method (hypothesis, test/artefact, evaluation) or similar engineering methods to discover new approaches to create new knowledge and achieve research or organizational goals.	Match elements of scientific or similar method and identify appropriate actions for organizational strategy to create new capabilities.	Apply scientific or similar method and develop action plans to translate organizational strategies to create new capabilities.	Evaluate methodologies to optimize the development of organizational objectives.
LO4.01	DSRM01 - Create new understandings and capabilities by using the scientific method (hypothesis, test, and evaluation) or similar engineering research and development methods.	Match elements of scientific or similar method to a given problem	Apply scientific method to create a new understandings and capabilities.	Evaluate various methods and predict which method can optimize creation of new understandings and capabilities.
LO4.02	DSRM02 - Direct systematic study toward a fuller knowledge or understanding of the observable facts, and discovers new approaches to achieve research or organizational goals.	Choose observable facts from an existing study for a better understanding.	Apply systematic study toward a fuller knowledge or understanding of the observable facts.	Combine several methods to discover new approaches to achieve organizational goals.
LO4.03	DSRM03 - Undertakes creative work, making systematic use of investigation or experimentation, to discover or revise knowledge of reality, and uses this knowledge to devise new applications	Show creativity under guidance of a senior staff in discovering and revising knowledge.	Develop creative solutions using systematic investigation or experimentation to revise and discover knowledge.	Adapt common systematic investigation to design and plan creative work to discover or revise knowledge.
LO4.04	DSRM04 - Ability to translate strategies into action plans and follow through to completion.	Identify appropriate actions for a given strategies.	Develop actions and action plan to translate strategies.	Recommend effective action plans to translate strategies.
LO4.05	DSRM05 - Contribute to and influence the development of organizational objectives.	Identify possible points which influence development of organization	Identify critical points which influence development of organizational	Recommend strategies that optimize the development of organizational

		objectives.	objectives.	objectives.
LO4.06	DSRM06 - Apply ingenuity to complex problems, develop innovative ideas	Illustrate outstanding ideas to solve complex problems.	Identify non-standard solutions to solve complex problems.	Recommend cost effective solution to a complex problem.
Business Process Management				
LO5-BPM	DS-BPM - Use domain knowledge (scientific or business) to develop relevant data analytics applications, and adopt general Data Science methods to domain specific data types and presentations, data and process models, organisational roles and relations.	Match elements of a mathematical framework to a given business problem and operate data support services for other organizational roles.	Model business problems into an abstract mathematical framework and identify critical points which influence development of organizational objectives.	Evaluate various methods to predict which method can optimize solving business problems and recommend strategies that optimize the development of organizational objectives.
LO5.01	DSBPM01 - Understand business and provide insight, translate unstructured business problems into an abstract mathematical framework.	Match elements of a mathematical framework to a given business problem.	Model an unstructured business problem into an abstract mathematical framework.	Evaluate various methods and predict which method can optimize solving business problems.
LO5.02	DSBPM02 - Use data to improve existing services or develop new services.	Match data to specification of services.	Analyze services to develop data specification.	Assess and improve use of data in services.
LO5.03	DSBPM03 - Participate strategically and tactically in financial decisions that impact management and organizations.	Identify appropriate actions for management and organizational decisions.	Identify critical points which influence development of organizational objectives.	Recommend strategies that optimize the development of organizational objectives.
LO5.04	DSBPM04 - Provides scientific, technical, and analytic support services to other organizational roles.	Operate data support services for other organizational roles.	Develop data support services for other organizational roles.	Optimize data support services for other organizational roles.
LO5.05	DSBPM05 - Analyse customer data to identify/optimize customer relations actions.	Summarize customer data.	Survey and visualize customer data.	Recommend actions based on data analysis to improve customer relations.

4.4 Definition of MC-DS Learning Units

The following Table 3 provides an example of defining the Learning Units (LU) or courses that correspond to the Knowledge Areas Groups and Knowledge Units defined in the DS-BoK. The units or courses are defined in accordance with the existing classification of academic disciplines, in current case, with the ACM Classification Computer Science (2012) [12] and in most cases verified with the existing offered courses at universities.

The proposed LUs are grouped according to CCS2012 classification or DS-BoK knowledge groups/units that can be used as a context information for future Data Science curricula development, modification or enhancement with the linked courses and disciplines.

The table also provides suggestion of how individual LUs can be treated as Mandatory Tier 1 or Tier 2 or Elective.

The further development will include mapping between Learning Outcomes including proficiency or mastery level (after verified with experts and practitioners), competences related to professional profiles, and knowledge. This will allow constructing a customized MC-DS curriculum for individual learner groups or organizational needs.

The fully defined MC-DS will be linked to other components of the EDISON Data Science Framework such as educational materials inventory, certification scheme and services, and EDISON Online Educational Environment (EOEE, initial design is presented in Deliverable D3.2 [31]).

To do this work, the project will solicit contributions from the Data Science professional community, experts and champion universities (cf. Chapter **Error! Reference source not found.**).

Table 3 Example Learning Units (courses) and their mapping to CCS2012 based classification of Academic subject and to existing BoKs

KAG/ LU# (*)	Learning Unit (course name) ²	Type/relevance ³				Map to DS-BoK, CCS2012 and known BoKs	
		Tier 1	Tier 2	Elective	Pre requisite	CCS2012 based academic subjects	DS-BoK and other BoKs
	Design and Analysis of Algorithms					Theory of computation Design and analysis of algorithms Data structures design and analysis Theory and algorithms for application domains Machine learning theory Algorithmic game theory and mechanism design Database theory Semantics and reasoning	No specific BoK are defined
	Machine Learning Theory						
	Game Theory & Mechanism design						
	<i>Extensibility point for adding new courses</i>						
	Discrete Mathematics and Graph Theory					Mathematics of computing Discrete mathematics Graph theory Probability and statistics Probabilistic representations Probabilistic inference problems Probabilistic reasoning algorithms Probabilistic algorithms Statistical paradigms Mathematical software Information theory	No specific BoK are defined
	Probability & Statistics						
	Statistical methods, including descriptive statistics, exploratory data analysis (EDA) and confirmatory data analysis (CDA)						
	Data analytics (with R or Python)						

² Note1: The Learning Units presented in Table 3 are defined based on courses taught at universities (refer to Data Science programmes Inventory [47]). The courses or LU topics or scope are not exclusive, some courses may include or be a superset to other Learning Units. This will provide flexibility for MC-DS users: universities or training organisations, to select any set of Learning units to satisfy requirements of their target learner groups.

³ Note2: Learning Unit or course relevance is assigned to one of levels: Tier 1, Tier 2, elective or pre-requisite, where known based on information collected from the Data Science programmes inventory [47]. Some Learning units are left not assigned and will be a subject for future MC-DS development.

KAG/ LU# (*)	Learning Unit (course name) ²	Type/relevance ³				Map to DS-BoK, CCS2012 and known BoKs	
		Tier 1	Tier 2	Elective	Pre requisite	CCS2012 based academic subjects	DS-BoK and other BoKs
	Information theory					Mathematical analysis	
	Mathematical analysis						
	<i>Extensibility point for adding new courses</i>						
	Artificial Intelligence					Computing methodologies Artificial intelligence Natural language processing Knowledge representation and reasoning Search methodologies Machine learning Learning paradigms Supervised learning Unsupervised learning Reinforcement learning Multi-task learning Machine learning approaches Machine learning algorithms	No specific BoK are defined
	Natural Language Processing						
	Knowledge Representation and Reasoning						
	Data mining and knowledge discovery						
	Text analysis, Data mining						
	Text analytics including statistical, linguistic, and structural techniques to analyse structured and unstructured data						
	Machine Learning theory and algorithms						
	Classification methods						
	Decision Analysis and Decision Support Systems						
	Data warehousing and Data Mining						
	Data Analysis and statistics					Information systems Information systems applications Decision support systems Data warehouses Expert systems Data analytics Online analytical Multimedia information systems Data mining	No specific BoK are defined
	Multimedia information systems						
	Data Mining						
	Predictive analytics and predictive forecasting						

KAG/ LU# (*)	Learning Unit (course name) ²	Type/relevance ³				Map to DS-BoK, CCS2012 and known BoKs	
		Tier 1	Tier 2	Elective	Pre requisite	CCS2012 based academic subjects	DS-BoK and other BoKs
	Big Data: Algorithms for Data Preprocessing, Computational Intelligence, and Imbalanced Classes					DSDA Extension group Theory of computation DSA Extension point: Algorithms for Big Data computation Mathematics of computing DSA Extension point: Mathematical software for Big Data computation Computing methodologies DSA Extension point: New DSA computing Information systems DSA Extension point: Big Data systems (e.g. cloud based) Information systems applications DSA Extension point: Big Data applications DSA Extension point: Domain specific Data applications	Extended with new DSDA Knowledge Areas and corresponding academic subjects
	Big Data analytics and Hadoop						
	Big Data Analytics						
	Big Data systems						
	Big Data systems and applications in domain						
	Parallel and Distributed Computer Architecture					Computer systems organization Architectures Parallel architectures Distributed architectures Networks *) Network Architectures Network Services Cloud Computing	No specific BoK are defined
	Computer networks						
	Software (systems) architectures					Software and its engineering Software organization and properties Software system structures Software architectures Software system models Ultra-large-scale	No specific BoK are defined
	Cloud enabled applications development						

KAG/ LU# (*)	Learning Unit (course name) ²	Type/relevance ³				Map to DS-BoK, CCS2012 and known BoKs	
		Tier 1	Tier 2	Elective	Pre requisite	CCS2012 based academic subjects	DS-BoK and other BoKs
							programming languages
	Cloud Computing architecture and services					Extensions are suggested for DS-BoK: Information systems DSE Extension point: Big Data and cloud based systems design Information systems applications DSA Extension point: Big Data applications DSA Extension point: Domain specific Data applications	Infrastructure and platforms for Data Science applications group: CCENG - Cloud Computing Engineering (infrastructure and services design, management and operation) CCAS - Cloud based applications and services development and deployment BDA – Big Data Analytics platforms (including cloud based) BDI - Big Data Infrastructure services and platforms, including data storage infrastructure Data and applications security KAs: SEC - Applications and data security SSM – Security services management, including compliance and certification
	Cloud Computing Engineering (infrastructure and services design, management and operation)						
	Cloud based applications and services development and design						
	Cloud based applications and services operation and management						
	Big Data Analytics platforms (including cloud based)						
	Big Data and cloud based systems design						
	Big Data Infrastructure: services and components, including data storage infrastructure						
	Software requirements and design					Extensions are suggested from SWEBOK	SWEBOK selected KAs <ul style="list-style-type: none"> • Software requirements • Software design • Software construction • Software testing • Software maintenance • Software configuration
	Software engineering models and methods						
	Software quality assurance						
	Agile development methods, platforms and tools						

KAG/ LU# (*)	Learning Unit (course name) ²	Type/relevance ³				Map to DS-BoK, CCS2012 and known BoKs	
		Tier 1	Tier 2	Elective	Pre requisite	CCS2012 based academic subjects	DS-BoK and other BoKs
	DevOps and continuous deployment and improvement paradigm						management • Software engineering management • Software engineering process • Software engineering models and methods • Software quality Agile development technologies Methods, platforms and tools DevOps and continuous deployment and improvement paradigm
	<i>Extensibility point for adding new courses</i>						
	Database management systems					Information systems Data management systems Database design and models Data structures Database management system engines Query languages Database administration Middleware for databases Information integration	No specific BoK are defined
	Database design and models						
	Data Modelling, Databases and Database Management Systems						
	Data Models and Query Languages						
	Database administration						
	Digital libraries and archives					Information systems Information systems applications Digital libraries and archives Information retrieval Document representation Retrieval models and ranking Search engine architectures and scalability Specialized information retrieval	No specific BoK are defined
	Information Retrieval						
	<i>Extensibility point for adding new courses</i>						
	Data management, including Reference and Master Data						
						Extensions are suggested from DM-BoK	DM-BoK selected KAs (1) Data Governance,

KAG/ LU# (*)	Learning Unit (course name) ²	Type/relevance ³				Map to DS-BoK, CCS2012 and known BoKs	
		Tier 1	Tier 2	Elective	Pre requisite	CCS2012 based academic subjects	DS-BoK and other BoKs
	Data Warehousing and Business Intelligence						(2) Data Architecture, (3) Data Modelling and Design, (4) Data Storage and Operations, (5) Data Security, (6) Data Integration and Interoperability, (7) Documents and Content, (8) Reference and Master Data, (9) Data Warehousing and Business Intelligence, (10) Metadata, and (11) Data Quality.
	Data storage and operations						
	Data archives/storage compliance and certification						
	Metadata, linked data, provenance						
	Data infrastructure, data registries and data factories						
	Data security and protection						
	Data governance, data quality, data Integration and Interoperability						
	Data Management Planning						
	Responsible data use, data privacy, ethical principles, legal issues						
	Data type registries, PID, metadata					Extended with the general Data Management Knowledge Areas and related academic subjects.	General Data Management KA's Data Lifecycle Management Data archives/storage compliance and certification New KAs to support RDA recommendations and community data management models (Open Access, Open Data, etc) Data type registries, PIDs Data infrastructure and Data Factories TBD – To follow RDA and ERA community developments
	Research data infrastructure, Open Science, Open Data, Open Access, ORCID						
	<i>Extensibility point for adding new courses</i>						

KAG/ LU# (*)	Learning Unit (course name) ²	Type/relevance ³				Map to DS-BoK, CCS2012 and known BoKs	
		Tier 1	Tier 2	Elective	Pre requisite	CCS2012 based academic subjects	DS-BoK and other BoKs
	Research methodology, research cycle					Extended with the general Scientific/Research Methods subjects and related academic subjects.	Suggested KAs to develop DSRM related competences: Research methodology, research cycle (e.g. 4 step model Hypothesis – Research Methods – Artefact – Validation) Modelling and experiment planning Data selection and quality evaluation Use cases analysis: research infrastructures and projects TBD further extensions
	Modelling and experiment planning						
	Data selection and quality evaluation						
	Use cases analysis: research infrastructures and projects						
	<i>Extensibility point for adding new courses</i>						
	Business processes and operations					Extensions are suggested from PMI-BoK	PMI-BoK selected KAs Project Integration Management Project Scope Management Project Quality Project Risk Management
	Project scope and risk management						
	Business Analysis Planning and Monitoring					Extensions are suggested from BABOK	BABOK selected KAs *) Business Analysis Planning and Monitoring: describes the tasks used to organize and coordinate business analysis efforts. Requirements Analysis and Design Definition. Requirements Life Cycle Management (from inception to retirement). Solution Evaluation and improvements recommendation.
	Requirements Analysis and Design Definition						
	Requirements Life Cycle Management (from inception to retirement)						
	Solution Evaluation and improvements recommendation						
	Agile Data Driven methodologies, processes and enterprises					Extended with the general Business process management and operation subjects and related academic subjects.	General Business processes and operations KAs Business processes and operations

KAG/ LU# *)	Learning Unit (course name) ²	Type/relevance ³				Map to DS-BoK, CCS2012 and known BoKs	
		Tier 1	Tier 2	Elective	Pre requisite	CCS2012 based academic subjects	DS-BoK and other BoKs
	Use cases analysis: business and industry						Agile Data Driven methodologies, processes and enterprises Use cases analysis: business and industry TBD further extensions

*) Learning units enumeration and their relation to DS-BoK Knowledge Area Groups will be provided in the future release of MC-DS after collecting feedback from the Champion universities and other pilot implementations.

5 Example of using EDSF for Curricula Design and Evaluation































This section provides an example how the proposed EDISON Data Science Framework, in particular its components CF-DS, DS-BoK, MC-DS, and DSP profiles, can be used for designing a new Data Science curriculum or evaluating the existing curriculum for compliance to the selected Data Science professional profiles.

5.1 Designing a new programme

In practice when designing a new programme it is necessary to decide on the set of courses with a specific number of credits. The standard in Europe is to use European Credit Transfer System, which defines bachelor programs to have 180 points and Master programs 120 points. This gives usually 30 points per semester. At American institutions credit hours systems are used and they are not fully uniform between institutions. Therefore, we do not provide an explicit recalculation to this system here. It can be easily done for each institutions depending on the typical semester load and its proportion to 30 ECTS points.

Required proficiency in each competence group for each professional profile is summarized in **Table 4**. Data Science Professional profiles are described in deliverable D2.2 and competence groups in deliverable D2.1. It creates a basis for division of points between Learning Outcomes and related Learning Unit. In addition, each Learning Outcome can be achieved on three different knowledge or mastery levels (familiarity, usage, assessment). Typically, Bachelor programs focus on two lower levels and Master programs on two higher levels.

Table 4 Proficiency/mastery level needed by different Data Science Profile for each of Data Science competence groups

	Managers : DSP01-DS03	Professionals: DSP04-DS09	Professionals (data handling/management: DSP10-13	Professionals (database): DSP14-DS16	Technician and associate profession: DSP17-DS19
Data analytics					
Data Science Engineering					
Data Management					
Scientific research and method					
Business process					
Domain Knowledge					

Legend:

1. Bars represent individual DSP profiles
2. color represent mastery level: familiarity –light blue; usage- blue; assessment – dark blue.

The following Table 5 provides example distribution of ECTS point between competence groups for Data Science professional profiles.

Table 5 ECTS point assignment to competence groups for professional profile groups (example)

Competence Group	DSP01-03 (Managers)	DSP04-09 (Professionals Data Science)	DSP10-13 (Professionals Data Handling/Manag ement)	DSP14-16 (Professionals databases)	DSP17-19 (Technician and Associate)

	BSc	MSc	BSc	MSc	BSc	MSc	BSc	MSc	BSc	MSc
DSDA Data Analytics		30	55	35	30	20	25	15	15	
DS-ENG Data Science Engineering		20	55	35	50	30	115	75	135	
DSDK Domain Knowledge		20	55	35	80	50	25	15	15	
DSDM Data Management		30	5	5	10	10	10	10	10	
DSRM Scientific Research Methods/ DSBPM Business Process		10	10	10	10	10	5	5	5	
		120	180	120	180	120	180	120	180	

Table 6 presents an exemplary distribution of ECTS points between specific Learning Outcomes and related Learning Units for Data Science Professional group DSP04-DSP09. The total amount of ECTS points for all learning outcomes in a specific competence group is based on the high levels distribution in Table 5. Distribution to specific Learning Outcomes results from the importance of related Learning Units which can belong to different tiers (Tier-1, Tier-2, Elective).

Details for other DSP professional groups can be found in Appendix D. Example ECTS points assignment to different Data Science Professional groups.

Table 6 Distribution of ECTS credit points between specific learning outcomes for profiles DSP04-09

LO ID	Data Science Competence	ECTS credit points by Knowledge levels.					
		Familiarity		Usage		Creation	
		BSc	MSc	BSc	MSc	BSc	MSc
Data Science Data Analytics							
LO1-DA	DSDA-DA - Use appropriate statistical techniques and predictive analytics on available data to deliver insights and discover new relations.	30		25	30		25
LO1.01	DSDA01 - Use predictive analytics to analyze big data and discover new relations.	5		5	5		5
LO1.02	DSDA02 - Use appropriate statistical techniques on available data to deliver insights.	5		5	5		
LO1.03	DSDA03 - Develop specialized analytics to enable agile decision making.	5		5	5		5
LO1.04	DSDA04 - Research and analyze complex data sets, combine different sources and types of data to improve analysis.	5		5	5		5
LO1.05	DSDA05 - Use different data analytics platforms to process complex data.	5		5	5		5

LO ID	Data Science Competence	ECTS credit points by Knowledge levels.					
		Familiarity		Usage		Creation	
		BSc	MSc	BSc	MSc	BSc	MSc
LO1.06	DSDA06 - Visualise complex and variable data.	5			5		5
Data Science Data Management							
LO2-DM	DSDM-DM - Develop and implement data management strategy for data collection, storage, preservation, and availability for further processing.			5			5
LO2.01	DSDM01 - Develop and implement data strategy, in particular, in a form of Data Management Plan (DMP).						
LO2.02	DSDM02 - Develop and implement relevant data models, including metadata.			2			2
LO2.03	DSDM03 - Collect and integrate different data source and provide them for further analysis.			2			2
LO2.04	DSDM04 - Develop and maintain a historical data repository of analysis results (data provenance).			1			1
LO2.05	DSDM05 - Ensure data quality, accessibility, publications (data curation).						
LO2.06	DSDM06 - Manage IPR and ethical issues in data management.						
Data Science Engineering							
LO3-ENG	DSENG-ENG - Use engineering principles to research, design, develop and implement new instruments and applications for data collection, analysis and management.	25		30	25		30
LO3.01	DSENG01 - Use engineering principles to research, design, prototype data analytics applications, or develop structures, instruments, machines, experiments, processes, systems.	5		10	5		10
LO3.02	DSENG02 - Develop and apply computational solutions to domain related problems using wide range of data analytics platforms.	5		5	5		5
LO3.03	DSENG03 - Develops specialized data analysis tools to support executive decision making.	5		5	5		5
LO3.04	DSENG04 - Design, build, operate database technologies.	5		5	5		5
LO3.05	DSENG05 - Develop solutions for secure and reliable data access.						
LO3.06	DSENG06 - Prototype new data analytics applications.	5		5	5		5
Data Science Research Methods							
LO4-RM	DSRM-RM - Create new understandings and capabilities by using the scientific method (hypothesis, test/artefact, evaluation) or similar engineering methods to discover new approaches to create new knowledge and achieve research or organizational goals.	5		5	5		5

LO ID	Data Science Competence	ECTS credit points by Knowledge levels.					
		Familiarity		Usage		Creation	
		BSc	MSc	BSc	MSc	BSc	MSc
LO4.01	DSRM01 - Create new understandings and capabilities by using the scientific method (hypothesis, test, and evaluation) or similar engineering research and development methods.	2		2			2
LO4.02	DSRM02 - Direct systematic study toward a fuller knowledge or understanding of the observable facts, and discovers new approaches to achieve research or organizational goals.	2		2	2		2
LO4.03	DSRM03 - Undertakes creative work, making systematic use of investigation or experimentation, to discover or revise knowledge of reality, and uses this knowledge to devise new applications				2		
LO4.04	DSRM04 - Ability to translate strategies into action plans and follow through to completion.						1
LO4.05	DSRM05 - Contribute to and influence the development of organizational objectives.				1		
LO4.06	DSRM06 - Apply ingenuity to complex problems, develop innovative ideas	1		1			
Business Process Management							
LO5-BPM	DSBPM-BPM - Use domain knowledge (scientific or business) to develop relevant data analytics applications, and adopt general Data Science methods to domain specific data types and presentations, data and process models, organisational roles and relations.	5		5	5		5
LO5.01	DSBPM01 - Understand business and provide insight, translate unstructured business problems into an abstract mathematical framework.	2		2	2		2
LO5.02	DSBPM02 - Use data to improve existing services or develop new services.	2		2	1		2
LO5.03	DSBPM03 - Participate strategically and tactically in financial decisions that impact management and organizations.						
LO5.04	DSBPM04 - Provides scientific, technical, and analytic support services to other organizational roles.						
LO5.05	DSBPM05 - Analyse customer data to identify/optimize customer relations actions.	1		1	2		1
LO5.06	DSBPM06 - Analyse multiple data sources for marketing purposes.						

5.2 Assessment of existing programmes and identification of potential gaps

Another important and useful use of the presented MC-DS is the possibility to assess the existing Data Science programmes for compliance with the proposed MC-DS and make their fine tuning for target Data Science professional profiles that are defined based on the ESCO Taxonomy [32] (see DSP profiles definition in D2.2 [3])

and discussion document [7]). Such use of the DS-MC will help to close the gap between the offered Data Science education and demand from the job market.

Preliminary study of a few existing Data Science programs from the EDISON Data Science programs inventory list [50] and programmes developed by the EDISON Champion universities allowed us to make few observations. The best existing programmes and those developed by the Champions are primarily covering the required competences profiles DSP04-DSP09 for Data Science Professional and profiles DSP01-DSP03 for Data Science Managers (see [3] and [7] for DSP taxonomy and hierarchy). However competences related to Data Management are not explicitly covered in most of existing Computer Science based programmes which are primarily reviewed in the project⁴. DSP10-DSP13 profiles primarily dealing with data management, curation, digital archiving and digital libraries are offered by non-Computer Science departments and their experience and offerings still to be studied by the project with the purpose to create consistent Data Science programmes covering both Computer Science based programmes and those educating digital librarians, archivists and curators. Taking into account that Data Management competences will be required for all DSP professional groups, necessary training can be offered at post-graduate stage or at working place.

Together with the EDISON champion universities, we are trying to identify if their respective DS programmes are covering all DS competencies groups and with the right mastery level. As a result, new courses and trainings will be added to the existing programs. Another approach to close courses gap considered by the EDISON champions is to establish a Data Science Erasmus exchange program across some of the EDISON champions to enable the DS graduates to move across the different universities to complete the missing competences.

⁴ This gap is recognized in the project and efforts has been taken to initiate a reference Data Management curriculum and modular course developments at the University of Amsterdam under umbrella of the Research Data Alliance initiative on Research Data Management Literacy initiative that will host the BoF meeting at the next RDA8 Plenary meeting in Denver on 15-17 September 2016.

6 Conclusion and further developments

The presented initial definition of the Data Science Model Curriculum (MC-DS) have been done with wide consultation and engagement of different stakeholders, primarily from research community and Research Infrastructures, but also involving industry via standardisation bodies, professional communities and directly via the project network.

6.1 Summary of findings

The Data Science Model Curriculum is a core component of the EDISON Data Science Framework that connects all components into a comprehensive tool aimed at supporting universities and professional training organizations in the development of new Data Science programmes, but also in the assessment of existing programmes w.r.t. coverage of competencies and knowledge areas associated with specific professional profiles/occupations.

The presented MC-DS is built around the DS-BoK and uses the existing classification of the academic disciplines, at this stage, mostly defined by the ACM Classification of Computer Science CCS2012.

The presented MC-DS intends to provide a guidance and a basis for universities to define their Data Science curricula and help with the individual courses selection. Together with DSP competence profiles, the MC-DS will help companies to correctly specify requirements to their staff knowledge and provide necessary training for the career development of their staff.

The approach and first draft of the proposed Model Curriculum has been presented and discussed at the EDISON Champions Conference on (13-14 July 2016, New Forest, UK). The internal Champions demonstrated the application of the Data Science Competence Framework and Body of Knowledge components for developing their own Data Science programmes and other academic offerings, providing valuable insights, comments, and suggestions that have been incorporated into the current MC-DS version that will be further presented to the ELG meeting that is planned for 27 September 2016.

6.2 Further developments to formalize MC-DS and DS-BoK

It is anticipated that the presented here the first versions of the Data Science Body of Knowledge will require further development and validation by experts and communities of practice that will include the following specific tasks and activities:

- Collect feedback on the Data Science Model Curriculum initial version further improvement and extension.
- Engage with the partner and champion universities into pilot implementation of MC-DS and DS-BoK and collecting feedback from practitioners.
- Define specific knowledge areas related to the identified knowledge area groups by involving experts in the related knowledge areas, possibly also engaging with the specific professional communities such as IEEE, ACM, DAMA, IIBA, etc.
- Finalise the taxonomy of Data Science related knowledge areas and scientific disciplines based on ACM CCS (2012), provide suggestion for new knowledge areas and classifications classes.

Validation is an important part of the products that could be widely accepted by community. Validation of the proposed MC-DS and DS-BoK will be done in two main ways. First is presenting the proposed development to the communities of practice and soliciting feedback and contribution from the academic and professional community, including experts' interviews. The second way suggests involving the champion universities into validation and pilot implementation of the proposed DS-BoK and Model Curriculum.

It is anticipated that real life implementation and adoption of the EDISON Data Science framework will includes both approaches top-down and bottom-up that will allow universities and professional training institutions to benefit from EDISON recommendations and adopt them to available expertise, resources and demand of the Data Science competences and skills.

To ensure successful acceptance of the proposed EDSF and its core components, essential role belong to standardisation in the related technology and educational domains. This work is being done in the project. Necessary contacts with the European and international standardisation bodies and professional organisations are being established.

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Acronyms

Acronym	Explanation
ACM	Association for Computer Machinery
BABOK	Business Analysis Body of Knowledge
CCS	Classification Computer Science by ACM
CF-DS	Data Science Competence Framework
CODATA	International Council for Science: Committee on Data for Science and Technology
CS	Computer Science
DM-BoK	Data Management Body of Knowledge by DAMAI
DS-BoK	Data Science Body of Knowledge
EDSA	European Data Science Academy
EOEE	EDISON Online E-Learning Environment
ETM-DS	Data Science Education and Training Model
EUDAT	http://eudat.eu/what-eudat
EGI	European Grid Initiative
ELG	EDISON Liaison Group
EOSC	European Open Science Cloud
ERA	European Research Area
ESCO	European Skills, Competences, Qualifications and Occupations
EUA	European Association for Data Science
HPCS	High Performance Computing and Simulation Conference
ICT	Information and Communication Technologies
IEEE	Institute of Electrical and Electronics Engineers
IPR	Intellectual Property Rights
LERU	League of European Research Universities
LIBER	Association of European Research Libraries
MC-DS	Data Science Model Curriculum
NIST	National Institute of Standards and Technologies of USA
PID	Persistent Identifier
PM-BoK	Project Management Body of Knowledge
PRACE	Partnership for Advanced Computing in Europe
RDA	Research Data Alliance
SWEBOK	Software Engineering Body of Knowledge

Appendix A. Mastery levels

This appendix provides short overview and compare definition of mastery levels as used in the European Qualifications Framework (EQF) [25], e-CF, ACM/IEEE guidelines for Computer Science curriculum [6] and Bloom's taxonomy. It is used for the definition of mastery levels (also called proficiency levels in e-CF) necessary to define Learning Outcomes in MC-DS.

The European qualification framework [25] defines eight levels of knowledge achieved through stages of education. Level 6 is considered to be achieved through a bachelor degree, level 7 through a master's degree and level 8 through a PhD degree. Levels 3-8 are mapped to 5 levels in e-CF dimension 3. The mapping and description is presented in Table 7. By comparing e-CF levels directly with education requirements from EQF we can notice a certain mismatch. It is impossible to achieve a desired e-CF level by simply following an education path based on EQF. It is not enough to get a master's degree to become a Lead Professional. Rather, education requirements should be interpreted as a necessary condition, but not sufficient.

Table 7 Description of EQF and e-CF levels

EQF level	EQF level description	e-CF level	e-CF level description
8	Knowledge at the most advanced frontier, the most advanced and specialized skills and techniques to solve critical problems in research and/or innovation, demonstrating substantial authority, innovation, autonomy, scholarly or professional integrity.	e-5	Principal Overall accountability and responsibility; recognized inside and outside the organization for innovative solutions and for shaping the future using outstanding leading edge thinking and knowledge.
7	Highly specialized knowledge, some of which is at the forefront of knowledge in a field of work or study, as the basis for original thinking, critical awareness of knowledge issues in a field and at the interface between different fields, specialized problem-solving skills in research and/or innovation to develop new knowledge and procedures and to integrate knowledge from different fields, managing and transforming work or study contexts that are complex, unpredictable and require new strategic approaches, taking responsibility for contributing to professional knowledge and practice and/or for reviewing the strategic performance of teams.	e-4	Lead Professional/Senior Manager Extensive scope of responsibilities deploying specialized integration capability in complex environments; full responsibility for strategic development of staff working in unfamiliar and unpredictable situations.
6	Advanced knowledge of a field of work or study, involving a critical understanding of theories and principles, advanced skills, demonstrating mastery and innovation in solving complex and unpredictable problems in a specialized field of work or study, management of complex technical or professional activities or projects, taking responsibility for decision-making in unpredictable work or study contexts, for continuing personal and group professional development.	e-3	Senior Professional/Manager Respected for innovative methods and use of initiative in specific technical or business areas; providing leadership and taking responsibility for team performances and development in unpredictable environments.
5	Comprehensive, specialized, factual and theoretical knowledge within a field of work or study and an awareness of the boundaries of that knowledge, expertise in a comprehensive range of cognitive and practical skills in developing creative solutions to abstract problems, management and supervision in contexts where there is unpredictable change,	e-2	Professional Operates with capability and independence in specified boundaries and may supervise others in this environment; conceptual and abstract model building using creative thinking; uses theoretical knowledge

EQF level	EQF level description	e-CF level	e-CF level description
	reviewing and developing performance of self and others.		and practical skills to solve complex problems within a predictable and sometimes unpredictable context.
4	Factual and theoretical knowledge in broad contexts within a field of work or study, expertise in a range of cognitive and practical skills in generating solutions to specific problems in a field of work or study, self-management not within the guidelines of work or study contexts that are usually predictable, but are subject to change, supervising the routine work of others, taking some responsibility for the evaluation and improvement of work or study activities.		
3	Knowledge of facts, principles, processes and general concepts, in a field of work or study, a range of cognitive and practical skills in accomplishing tasks. Problem solving with basic methods, tools, materials and information, responsibility for completion of tasks in work or study, adapting own behaviour to circumstances in solving problems.	e-1	Associate Able to apply knowledge and skills to solve straight forward problems; responsible for own actions; operating in a stable environment.

EQF descriptions provide reference both to actual levels of knowledge, but also to additional skills related to knowledge application, analysis, synthesis and evaluation. It is quite similar to Bloom's approach. At the same time, levels in EQF do not only correspond to higher levels of conceptualization, but also to more specialized knowledge, experience and interpersonal skills related to people management, and professional integrity and responsibility. e-CF adds to its description of typical tasks regarding their complexity and autonomy. Therefore, higher levels of EQF and e-CF should not just be seen directly as the same higher levels in Bloom. At the same time, higher levels in Bloom's taxonomy are necessary to move up in e-CF and EQF. It follows the earlier argument about education requirements forming necessary but not sufficient conditions.

EQF has 8 levels, e-CF has 5 levels and Bloom's has 6 levels. Designing LOs of whole programs is a balance between precision and avoiding micromanagement of further definition of courses, especially when designing a guideline for programs instead of a specific program. It might be useful to limit the amount of levels on which LOs are considered. Such an approach is used in ACM/IEEE Computer Science and Information Technology curricula guidelines. Information Technology guidelines [7] define the three levels as: emerging, developed and highly developed. Computer Science guidelines [6] define the three levels as: familiarity, usage, and assessment. Bloom's taxonomy defines the six levels: knowledge, comprehension, application, analysis, synthesis and evaluation.

The three levels as used in ACM/IEEE Computer Science guidelines are of particular importance because significant parts of a related taxonomy and BoK is used in the definition of CF-DS and BoK-DS in EDISON. A description of these three levels is presented in **Error! Reference source not found..** The verb usage is not fully consistent with the original Bloom's taxonomy [16] or revised version, which is acknowledged in the document.

In principle, these levels are useful, though the synthesis level of Bloom's taxonomy seems to be somewhat omitted both in the naming of levels and also in their description. Furthermore, the analysis level of Bloom's taxonomy is sometimes mixed with the evaluation level. Deeper inspection suggests that ACM/IEEE's familiarity level maps to knowledge and comprehension levels in Bloom's taxonomy. Further, usage level in ACM/IEEE maps to analysis level in Bloom's taxonomy; and finally, assessment level in ACM/IEEE maps to analysis level in Bloom's taxonomy. As a result, synthesis and evaluation levels from Bloom's taxonomy are to a large extent omitted. Such omission might be acceptable for undergraduate curricula that ACM and IEEE consider in these documents.

Table 8 ACM/IEEE CS curricula master levels

Level	Description
Familiarity	The student understands what a concept is or what it means. This level of mastery concerns a basic awareness of a concept as opposed to expecting real facility with its application. It provides an answer to the question “What do you know about this?”
Usage	The student is able to use or apply a concept in a concrete way. Using a concept may include, for example, appropriately using a specific concept in a program, using a particular proof technique, or performing a particular analysis. It provides an answer to the question “What do you know how to do?”
Assessment	The student is able to consider a concept from multiple viewpoints and/or justify the selection of a particular approach to solve a problem. This level of mastery implies more than using a concept; it involves the ability to select an appropriate approach from understood alternatives. It provides an answer to the question “Why would you do that?”

While not required in undergraduate curricula, the holistic definition covering all EQF, e-CF levels, requires also full coverage of levels in Bloom’s taxonomy. At the same time, limitation to 3 levels should be maintained to preserve simplicity and compatibility. We suggest the following three levels: familiarity as understood by knowledge and comprehension in Bloom’s taxonomy, usage as understood by application and analysis in Bloom’s taxonomy, creation as understood by synthesis and evaluation in Bloom’s taxonomy. We present the three levels together with action verbs in Table 9. Action verbs were defined based on the original and revised Bloom’s taxonomy with adjustments tailored to Data Science curricula.

Table 9 Knowledge levels for learning outcomes in Data Science model curricula (MC-DS)

Level	Action Verbs
Familiarity	Choose, Classify, Collect, Compare, Configure, Contrast, Define, Demonstrate, Describe, Execute, Explain, Find, Identify, Illustrate, Label, List, Match, Name, Omit, Operate, Outline, Recall, Rephrase, Show, Summarize, Tell, Translate
Usage	Apply, Analyze, Build, Construct, Develop, Examine, Experiment with, Identify, Infer, Inspect, Model, Motivate, Organize, Select, Simplify, Solve, Survey, Test for, Visualize
Assessment	Adapt, Assess, Change, Combine, Compile, Compose, Conclude, Criticize, Create, Decide, Deduct, Defend, Design, Discuss, Determine, Disprove, Evaluate, Imagine, Improve, Influence, Invent, Judge, Justify, Optimize, Plan, Predict, Prioritize, Prove, Rate, Recommend, Solve

Appendix B. Subset of ACM/IEEE CCS2012 for Data Science

The presented taxonomy although based on ACM CCS (2012) classification can provide a basis and motivation for its extension with a new classification group related to Data Science and individual disciplines that are currently missing in the current ACM classification. This work will be a subject for future development and the results will be presented in other project deliverables.

B.1. ACM Classification Computer Science (2012) structure and Data Science related Knowledge Areas

The 2012 ACM Computing Classification System (CCS) [7] has been developed as a poly-hierarchical ontology that can be utilized in semantic web applications. It replaces the traditional 1998 version of the ACM Computing Classification System (CCS), which has served as the de facto standard classification system for the computing field for many years (also been more human readable). The ACM CCS (2012) is being integrated into the search capabilities and visual topic displays of the ACM Digital Library. It relies on a semantic vocabulary as the single source of categories and concepts that reflect the state of the art of the computing discipline and is receptive to structural change as it evolves in the future. ACM provides a tool within the visual display format to facilitate the application of 2012 CCS categories to forthcoming papers and a process to ensure that the CCS stays current and relevant.

However, at the moment none of Data Science, Big Data or Data Intensive Science technologies are reflected in the ACM classification. The following is an extraction of possible classification facets from ACM CCS (2012) related to Data Science what reflects multi-subject areas nature of Data Science:

As an example, the Cloud Computing that is also a new technology and closely related to Big Data technologies, currently is classified in ACM CCS (2012) into 3 groups:

Networks :: Network services :: Cloud Computing
Computer systems organization :: Architectures :: Distributed architectures :: Cloud Computing
Software and its engineering :: Software organization and properties :: Software Systems Structures :: Distributed systems organizing principles :: Cloud Computing

Taxonomy is required to consistently present information about scientific disciplines and knowledge areas related to Data Science. Taxonomy is important component to link such components as Data Science competences and knowledge areas, Body of Knowledge, and corresponding academic disciplines. From practical point of view, taxonomy includes vocabulary of names (or keywords) and hierarchy of their relations.

The presented here initial taxonomy of Data Science disciplines and knowledge areas is based on the 2012 ACM Computing Classification System (ACM CCS (2012)). Refer to initial analysis of ACM CCS (2012) classification and subset of data related disciplines in section B.1 and Table B.1. The presented in Table B.2 taxonomy includes ACM CCS (2012) subsets/subtrees that contain scientific disciplines that are related to Data Science Knowledge Area groups as defined in chapter 4 Data Science Body of Knowledge definition:

- KAG1-DSA: Data Analytics group including Machine Learning, statistical methods, and Business Analytics
- KAG2-DSE: Data Science Engineering group including Software and infrastructure engineering
- KAG3-DSDM: Data Management group including data curation, preservation and data infrastructure

Two other groups KAG4-DSRM: Scientific or Research Methods group and KAG5-DSBP: Business process management group cannot be mapped to ACM CCS (2012) and their taxonomy is not provided in this version. It is important to notice that ACM CCS (2012) provides a top level classification entry “Applied computing” that can be used as an extension point domain related knowledge area group KAG6-DSDK (see section 4.3 Knowledge Area groups definition).

The following approach was used when constructing the proposed taxonomy:

- ACM CCS (2012) provides almost full coverage of Data Science related knowledge areas or disciplines related to KAG1, KAG2, and KAG3. The following top level classification groups are used:

- Theory of computation
- Mathematics of computing
- Computing methodologies
- Information systems
- Computer systems organization
- Software and its engineering
- Each of KAGs includes subsets from few ACM CCS (2012) classification groups to cover theoretical, technology, engineering and technical management aspects.
- Extension points are suggested for possible future extensions of related KAGs together with their hierarchies.
- KAG3-DSDM: Data Management group is currently extended with new concepts and technologies developed by Research Data community and documented in community best practices.

Table 10 Data Science classification based on ACM Classification (2012)

DS-BoK Knowledge Groups *)	ACM (2012) Classification facets related to Data Science
Data Science Analytics (DSDA)	Theory of computation Design and analysis of algorithms Data structures design and analysis Theory and algorithms for application domains Machine learning theory Algorithmic game theory and mechanism design Database theory Semantics and reasoning
Data Science Analytics (DSDA)	Mathematics of computing Discrete mathematics Graph theory Probability and statistics Probabilistic representations Probabilistic inference problems Probabilistic reasoning algorithms Probabilistic algorithms Statistical paradigms Mathematical software Information theory Mathematical analysis
Data Science Analytics (DSDA)	Computing methodologies Artificial intelligence Natural language processing Knowledge representation and reasoning Search methodologies Machine learning Learning paradigms Supervised learning Unsupervised learning Reinforcement learning Multi-task learning Machine learning approaches Machine learning algorithms
Data Science Analytics (DSDA)	Information systems Information systems applications Decision support systems Data warehouses Expert systems Data analytics Online analytical processing Multimedia information systems Data mining
Data Science Analytics (DSDA) EXTENSION POINT	Theory of computation DSA Extension point: Algorithms for Big Data computation Mathematics of computing DSA Extension point: Mathematical software for Big Data computation Computing methodologies

DS-BoK Knowledge Groups *)	ACM (2012) Classification facets related to Data Science
	DSA Extension point: New DSA computing Information systems DSA Extension point: Big Data systems (e.g. cloud based) Information systems applications DSA Extension point: Big Data applications DSA Extension point: Domain specific Data applications
Data Science Data Management (DSDM)	Information systems Data management systems Database design and models Data structures Database management system engines Query languages Database administration Middleware for databases Information integration
Data Science Data Management (DSDM)	Information systems Information systems applications Digital libraries and archives Information retrieval Document representation Retrieval models and ranking Search engine architectures and scalability Specialized information retrieval
Data Science Data Management (DSDM) EXTENSION POINT	Information systems Data management systems Data types and structures description Metadata standards Persistent identifiers (PID) Data types registries
Data Science Engineering (DSE)	Computer systems organization Architectures Parallel architectures Distributed architectures
Data Science Engineering (DSENG)	Networks **) <ul style="list-style-type: none"> Network Architectures Network Services Cloud Computing
Data Science Engineering (DSENG)	Software and its engineering <ul style="list-style-type: none"> Software organization and properties Software system structures Software architectures Software system models Ultra-large-scale systems Distributed systems organizing principles Cloud computing Grid computing Abstraction, modeling and modularity Real-time systems software Software notations and tools General programming languages Software creation and management
Data Science Engineering (DSENG)	Computing methodologies <ul style="list-style-type: none"> Modeling and simulation Model development and analysis Simulation theory Simulation types and techniques Simulation support systems
Data Science Engineering (DSENG)	Information systems <ul style="list-style-type: none"> Information storage systems Information systems applications Enterprise information systems Collaborative and social computing systems and tools
Data Science Engineering (DSENG) EXTENSION POINT	Software and its engineering <ul style="list-style-type: none"> Software organization and properties DSE Extension point: Big Data applications design Data Analytics programming languages Information systems <ul style="list-style-type: none"> DSE Extension point: Big Data and cloud based systems design

DS-BoK Knowledge Groups *)	ACM (2012) Classification facets related to Data Science
	Information systems applications DSA Extension point: Big Data applications DSA Extension point: Domain specific Data applications
DS Domain Knowledge (DSDK) EXTENSION POINT	Applied computing Physical sciences and engineering Life and medical sciences Law, social and behavioral sciences Computer forensics Arts and humanities Computers in other domains Operations research Education Document management and text processing

*) All Acronyms for classification groups and DS-BoK Knowledge Area Groups are brought in accordance to CF-DS-competence groups

**) Due to important role of the Internet and networking technologies, basic knowledge about networks are required. However, as a technology domain, Networks knowledge area group should be considered as a domain specific knowledge area in the general Data Science competences and knowledge definition.

Appendix C. Data Science Body of Knowledge (DS-BoK) definition

The DS-BoK is defined based on the proposed competences model CF-DS that identified five competence areas that should be mapped into corresponding knowledge areas and groups (refer to the recent CF-DS version online⁵ [1], it is also included into Appendix C for details and visual presentation in Figure C.1 (a) and (b). The DS-BoK definition requires combination and synthesis of different domain knowledge areas with necessary selection or adaptation of educational and instructional models and practices.

C.1. DS-BoK structure and Knowledge Area Groups

The intended DS-BoK can be used as a base for defining Data Science related curricula, courses, instructional methods, educational/course materials, and necessary practices for university post and undergraduate programs and professional training courses. The DS-BoK is also intended to be used for defining certification programs and certification exam questions. While CF-DS (comprising of competences, skills and knowledge) can be used for defining job profiles (and correspondingly content of job advertisements) the DS-BoK can provide a basis for interview questions and evaluation of the candidate's knowledge and related skills.

Following the CF-DS competence group definition the DS-BoK should contain the following Knowledge Area groups (KAG):

- KAG1-DSDA: Data Analytics group including Machine Learning, statistical methods, and Business Analytics
- KAG2-DSENG: Data Science Engineering group including Software and infrastructure engineering
- KAG3-DSDM: *Data Management group including data curation, preservation and data infrastructure*
- KAG4-DSRM: *Scientific or Research Methods group*
- KAG5-DSBPM: Business process management group
- KAG6-DSDK: Data Science Domain Knowledge group includes domain specific knowledge

The subject domain related knowledge group (scientific or business) KAG6-DSDK is recognized as essential for practical work of Data Scientist what in fact means not professional work in a specific subject domain but understanding the domain related concepts, models and organisation and corresponding data analysis methods and models. These knowledge areas will be a subject for future development in tight cooperation with subject domain specialists.

It is also anticipated that due to complexity of Data Science domain, the DS-BoK will require wide spectrum of background knowledge, first of all in mathematics, statistics, logics and reasoning as well as general computing and cloud computing in particular. Similar to the ACM CS2013 curricula approach, background knowledge can be required as an entry condition or must be studied as elective courses.

Although in current version the proposed DS-BoK is using the ACM Computer Science BoK, it is important to mention that the domain oriented BS-BoK may be primarily defined by the specific domain needs and contain less ICT and Computer Science components.

The proposed DS-BoK definition uses the following BoK's to define the selected DS-BoK knowledge groups: Software Engineering SWEBOK, Business Analysis BABOK, and Project Management PM-BoK, and others.

Table 11 Identified DS-BoK Knowledge Area Groups

KA Groups	Knowledge Areas (KA) from existing BoKs	Additional Knowledge Areas
KAG1-DSDA: Data Analytics group including Machine Learning, statistical methods, and Business Analytics	BABOK selected KAs *) <ul style="list-style-type: none"> • Business Analysis Planning and Monitoring: describes the tasks used to organize and coordinate business analysis efforts. • Requirements Analysis and Design Definition. 	General Data Analytics and Machine Learning KAs <ul style="list-style-type: none"> • Machine learning and related methods • Predictive analytics and predictive forecasting

⁵ <http://www.edison-project.eu/data-science-competence-framework-cf-ds>

KA Groups	Knowledge Areas (KA) from existing BoKs	Additional Knowledge Areas
	<ul style="list-style-type: none"> Requirements Life Cycle Management (from inception to retirement). Solution Evaluation and improvements recommendation. 	<ul style="list-style-type: none"> Classification methods Data mining and knowledge discovery Business intelligence covers data analysis that relies heavily on aggregation and different data sources and focusing on business information; Text analytics including statistical, linguistic, and structural techniques to analyse structured and unstructured data Statistical methods, including descriptive statistics, exploratory data analysis (EDA) and confirmatory data analysis (CDA)
KAG2-DSENG: Data Science Engineering group including Software and infrastructure engineering	<p>ACM CS-BoK selected KAs:</p> <p>AL - Algorithms and Complexity</p> <p>AR - Architecture and Organization (including computer architectures and network architectures)</p> <p>CN - Computational Science</p> <p>GV - Graphics and Visualization</p> <p>IM - Information Management</p> <p>PBD - Platform-based Development (new)</p> <p>SE - Software Engineering (extended with SWEBOK KAs)</p> <p>SWEBOK selected KAs</p> <ul style="list-style-type: none"> Software requirements Software design Software construction Software engineering process Software engineering models and methods Software quality 	<p>Infrastructure and platforms for Data Science applications group:</p> <p>CCENG - Cloud Computing Engineering (infrastructure and services design, management and operation)</p> <p>CCAS - Cloud based applications and services development and deployment</p> <p>BDA – Big Data Analytics platforms (including cloud based)</p> <p>BDI - Big Data Infrastructure services and platforms, including data storage infrastructure</p> <p>Data and applications security KAs:</p> <p>SEC - Applications and data security</p> <p>SSM – Security services management, including compliance and certification</p> <p>Agile development technologies</p> <ul style="list-style-type: none"> Methods, platforms and tools DevOps and continuous deployment and improvement paradigm
KAG3-DSDM: Data Management group including data curation, preservation and data infrastructure	<p>DM-BoK selected KAs</p> <p>(1) Data Governance,</p> <p>(2) Data Architecture,</p> <p>(3) Data Modelling and Design,</p> <p>(4) Data Storage and Operations,</p> <p>(5) Data Security,</p> <p>(6) Data Integration and Interoperability,</p> <p>(7) Documents and Content,</p> <p>(8) Reference and Master Data,</p> <p>(9) Data Warehousing and Business Intelligence,</p> <p>(10) Metadata, and</p> <p>(11) Data Quality.</p>	<p>General Data Management KA's</p> <ul style="list-style-type: none"> Data Lifecycle Management Data archives/storage compliance and certification <p>New KAs to support RDA recommendations and community data management models (Open Access, Open Data, etc)⁶</p> <ul style="list-style-type: none"> Data type registries, PIDs Data infrastructure and Data Factories TBD – To follow RDA and ERA community developments

⁶ Example courses provided by RDA community and shared between European Research Infrastructures <https://europe.rd-alliance.org/training-programme>

KA Groups	Knowledge Areas (KA) from existing BoKs	Additional Knowledge Areas
KAG4-DSRM: Scientific or Research Methods group	There are no formally defined BoK for research methods	Suggested KAs to develop DSRM related competences: <ul style="list-style-type: none"> • Research methodology, research cycle (e.g. 4 step model Hypothesis – Research Methods – Artefact – Validation) • Modelling and experiment planning • Data selection and quality evaluation • Use cases analysis: research infrastructures and projects • TBD further extensions
KAG5-DSBPM: Business process management group	<p>PMI-BoK selected KAs</p> <ul style="list-style-type: none"> • Project Integration Management • Project Scope Management • Project Quality • Project Risk Management <p>BABOK selected KAs *)</p> <ul style="list-style-type: none"> • Business Analysis Planning and Monitoring: describes the tasks used to organize and coordinate business analysis efforts. • Requirements Analysis and Design Definition. • Requirements Life Cycle Management (from inception to retirement). • Solution Evaluation and improvements recommendation. 	<p>General Business processes and operations KAs</p> <ul style="list-style-type: none"> • Business processes and operations • Agile Data Driven methodologies, processes and enterprises • Use cases analysis: business and industry • TBD further extensions

*) BABOK KA are more business focused and related to KAG5-DSBP, however its specific topics related to data analysis can be reflected in the KAG1-DSDA

C.2. Data Science Body of Knowledge Areas and Knowledge Units

Presented analysis allows us to propose an initial version of the Data Science Body of Knowledge implementing the proposed DS-BoK structure as explained in previous section. Table 4.1 provides consolidated view of the identified Knowledge Areas in the Data Science Body of Knowledge. The table contains detailed definition of the KAG1-DSA, KAG2-DSE, KAG3-DSDM groups that are well supported by existing BoK's and academic materials. General suggestions are provided for KAG4-DSRM, KAG5-DSBP groups that corresponds to newly identified competences and knowledge areas and require additional study of existing practices and contribution from experts in corresponding scientific or business domains.

The KAG2-DSE group includes selected KAs from ACM CS-BoK and SWEBOOK and extends them with new technologies and engineering technologies and paradigm such as cloud based, agile technologies and DevOps that are promoted as continuous deployment and improvement paradigm and allow organisation implement agile business and operational models.

The KAG3-DSDM group includes most of KAs from DM-BoK however extended it with KAs related to RDA recommendations, community data management models (Open Access, Open Data, etc) and general Data Lifecycle Management that is used as a central concept in many data management related education and training courses.

The presented DS-BoK high level content is not exhaustive at this stage and will undergo further development based on feedback from MC-DS implementation. The project will present the current version of DS-BoK to ELG to obtain feedback and expert opinion. Numerous experts will be invited to review and contribute to the specific KAs definition.

Table 12 Detailed definition of the DS-BoK and suggested Knowledge Units (KU)

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Suggested Knowledge Units (KU)	Mapping to CCS2012 (including suggested Data Science extensions) and existing BoKs
KAG1-DSDA: Data Analytics group (including Machine Learning, statistical methods)	Theory of computation	Design and Analysis of Algorithms	CCS2012: Theory of computation Design and analysis of algorithms Data structures design and analysis Theory and algorithms for application domains Machine learning theory Algorithmic game theory and mechanism design Database theory Semantics and reasoning
		Machine Learning Theory	
		Game Theory & Mechanism design	
		EXTENSIBILITY Point: Theory of computation	
	Mathematics of computing	Discrete Mathematics and Graph Theory	CCS2012: Mathematics of computing Discrete mathematics Graph theory Probability and statistics Probabilistic representations Probabilistic inference problems Probabilistic reasoning algorithms Probabilistic algorithms Statistical paradigms Mathematical software Information theory Mathematical analysis
		Probability & Statistics	
		Probabilistic reasoning	
		Statistical methods, including descriptive statistics, exploratory data analysis (EDA) and confirmatory data analysis (CDA)	
		Information theory	
		Mathematical analysis	
		Mathematical software and tools	
		EXTENSIBILITY Point: Mathematics of Data Science (computing)	TBD
	Computing methodologies	Artificial Intelligence	CCS2012: Computing methodologies Artificial intelligence Natural language processing Knowledge representation and reasoning Search methodologies Machine learning Learning paradigms Supervised learning Unsupervised learning Reinforcement Multi-task learning Machine learning approaches Machine learning algorithms
		Natural Language Processing	
		Knowledge Representation and Reasoning	
		Data mining and knowledge discovery	
		Text analysis, Data mining	
		Text analytics including statistical, linguistic, and structural techniques to analyse structured and unstructured data	
		Machine Learning theory and algorithms	
		Classification methods	
		EXTENSIBILITY Point: Computing methodologies	TBD
	Information systems (to support Data Science applications)	Decision Analysis and Decision Support Systems	CCS2012: Information systems Information systems applications Decision support systems Data warehouses Expert systems Data analytics Online analytical
		Data warehousing and Data Mining	
		Data Analysis and statistics	
		Multimedia information systems	

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Suggested Knowledge Units (KU)	Mapping to CCS2012 (including suggested Data Science extensions) and existing BoKs
		Data Mining	processing
		Predictive analytics and predictive forecasting	systems Multimedia information Data mining
		EXTENSIBILITY Point: Information systems	TBD
	Big Data Technologies and Systems	Big Data algorithm for large scale data processing	DSDA Extension group for CCS2012 Theory of computation DSA Extension point: Algorithms for Big Data computation Mathematics of computing DSA Extension point: Mathematical software for Big Data computation Computing methodologies DSA Extension point: New DSA computing Information systems DSA Extension point: Big Data systems (e.g. cloud based) Information systems applications DSA Extension point: Big Data applications DSA Extension point: Domain specific Data applications
		Big Data Analytics	
		Big Data systems	
		Big Data algorithms for data ingest, pre-processing, and visualisation	
		Big Data analytics platforms and tools (including Hadoop, Spark, and cloud based Big Data services)	
		Big Data systems for application domains	
		EXTENSIBILITY Point: Information systems	TBD
KAG2-DSENG: Data Science Engineering group including Software and infrastructure engineering	Computer systems organisation for Big Data applications (including high performance networks)	Parallel and Distributed Computer Architecture	CCS2012: Computer systems organization Architectures Parallel architectures Distributed architectures Networks *) Network Architectures Network Services Cloud Computing
		Computer networks: architectures and protocols	
		Computer networks for high-performance computing and Big Data infrastructure	
		EXTENSIBILITY Point:	TBD
	Big Data software organisation and engineering	Software (systems) architectures	CCS2012: Software and its engineering Software organization and properties Software system structures Software architectures Software system models Ultra-large-scale systems Distributed systems organizing principles Cloud computing Grid computing Abstraction, modeling and modularity Real-time systems software Software notations and tools General programming languages Software creation and management
		Requirements engineering and software systems development	
		Large and ultra-large scale software systems organisation	
		Cloud enabled applications development	

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Suggested Knowledge Units (KU)	Mapping to CCS2012 (including suggested Data Science extensions) and existing BoKs
		EXTENSIBILITY Point:	TBD
	Modelling and simulation	Modelling and simulation theory and techniques (general and domain oriented)	CCS2012: Computing methodologies Modeling and simulation Model development and analysis Simulation theory Simulation types and techniques Simulation support systems
		Large scale modelling and simulation systems	
		EXTENSIBILITY Point:	TBD
	Big Data systems organisation and management	Enterprise information systems	CCS2012: Information systems Information storage systems Information systems applications Enterprise information systems Collaborative and social computing systems and tools
		Large scale data storage and data management systems	
		Collaborative and social computing systems and tools	
		EXTENSIBILITY Point:	TBD
	Big Data (Data Science) applications design	Programming languages for Big Data analytics: R, python, others	Proposed new KA for DS-BoK Linked to KAG1-DSA DSDA: Big Data applications design DSDA: Data Analytics programming languages
		Models and languages for complex interlinked data presentation and visualisation	
		EXTENSIBILITY Point:	TBD
	Infrastructure and platforms for Data Science applications group:	Cloud Computing architecture and services	Proposed new KA for DS-BoK Infrastructure and platforms for Data Science applications group: CCENG - Cloud Computing Engineering (infrastructure and services design, management and operation) CCAS - Cloud based applications and services development and deployment BDA – Big Data Analytics platforms (including cloud based) BDI - Big Data Infrastructure services and platforms, including data storage infrastructure Data and applications security KAs: SEC - Applications and data security SSM – Security services management, including compliance and certification
		Cloud Computing Engineering (infrastructure and services design, management and operation)	
		Big Data and cloud based systems design and development	
		Cloud based applications and services operation and management	
		Big Data Analytics platforms (including cloud based)	
		Big Data Infrastructure: services and components, including data storage infrastructure	
		Data security and protection	
		EXTENSIBILITY Point:	TBD
	Software engineering and management	Software requirements and design	SWEBOK selected KAs <ul style="list-style-type: none"> • Software requirements • Software design • Software construction • Software testing • Software maintenance • Software configuration management • Software engineering management
		Software engineering models and methods	
		Software quality assurance	
		Agile development methods, platforms and tools	

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Suggested Knowledge Units (KU)	Mapping to CCS2012 (including suggested Data Science extensions) and existing BoKs
		DevOps and continuous deployment and improvement paradigm	<ul style="list-style-type: none"> Software engineering process Software engineering models and methods Software quality Agile development technologies <ul style="list-style-type: none"> Methods, platforms and tools DevOps and continuous deployment and improvement paradigm
		EXTENSIBILITY Point:	TBD
KAG3-DSDM: Data Management group (including data curation, preservation and data infrastructure)	Data management systems	Database management systems	CCS2012: Information systems Data management systems Database design and models Data structures Database management system engines Query languages Database administration Middleware for databases Information integration
		Database design and models	
		Data Modelling, Databases and Database Management Systems	
		Data Models and Query Languages	
		Database administration	
		EXTENSIBILITY Point:	TBD
	Digital libraries and archives	Digital libraries and archives organisation	CCS2012: Information systems Information systems applications Digital libraries and archives Information retrieval Document representation Retrieval models and ranking Search engine architectures and scalability Specialized information retrieval
		Information Retrieval	
		Data curation and provenance	
		Search Engines technologies	
		EXTENSIBILITY Point:	TBD
	Data Management and Enterprise data infrastructure	Data management, including Reference and Master Data	DM-BoK selected KAs (1) Data Governance, (2) Data Architecture, (3) Data Modelling and Design, (4) Data Storage and Operations, (5) Data Security, (6) Data Integration and Interoperability, (7) Documents and Content, (8) Reference and Master Data, (9) Data Warehousing and Business Intelligence, (10) Metadata, and (11) Data Quality.
		Data Warehousing and Business Intelligence	
		Data storage and operations	
		Data archives/storage compliance and certification	
		Metadata, linked data, provenance	
		Data infrastructure, data registries and data factories	
		Data security and protection	
		Data governance, data quality, data Integration and Interoperability	
		Data Management Planning	
		Responsible data use, data privacy, ethical principles, legal issues	
		EXTENSIBILITY Point:	TBD
	General principles and concepts in	Data type registries, PID, metadata	Proposed new KA for DS-BoK General Data Management KA's

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Suggested Knowledge Units (KU)	Mapping to CCS2012 (including suggested Data Science extensions) and existing BoKs
	Data Management and organisation	Research data infrastructure, Open Science, Open Data, Open Access, ORCID	<ul style="list-style-type: none"> • Data Lifecycle Management • Data archives/storage compliance and certification New KAs to support RDA recommendations and community data management models (Open Access, Open Data, etc) <ul style="list-style-type: none"> • Data type registries, PIDs • Data infrastructure and Data Factories • New KAs to follow RDA and ERA community developments
		Data infrastructure compliance and certification	
		Ethical principle and data privacy	
		EXTENSIBILITY Point:	TBD
KAG4-DSRM: Scientific and Research Methods group	Scientific/Research Methods	Research methodology, paradigms and research cycle	Proposed new KA for DS-BoK To develop DSRM related competences: <ul style="list-style-type: none"> • Research methodology, research cycle (e.g. 4 step model Hypothesis – Research Methods – Artefact – Validation) • Modelling and experiment planning • Data selection and quality evaluation • Use cases analysis: research infrastructures and projects • Research data management plan and ethical issues • TBD further extensions
		Modelling and experiment planning	
		Data selection and quality evaluation	
		Use cases analysis: research infrastructures and projects	
		Research data management plan and ethical issues	
		EXTENSIBILITY Point:	TBD
KAG5-DSBPM: Business process management group	Business Process Management	Business processes and operations	PMI-BoK selected KAs <ul style="list-style-type: none"> • Project Integration Management • Project Scope Management • Project Quality • Project Risk Management
		Project scope and risk management	
		EXTENSIBILITY Point:	TBD
	Business Analysis organisation and management	Business Analysis Planning and Monitoring	BABOK selected KAs <ul style="list-style-type: none"> • Business Analysis Planning and Monitoring: describes the tasks used to organize and coordinate business analysis efforts. • Requirements Analysis and Design Definition. • Requirements Life Cycle Management (from inception to retirement). • Solution Evaluation and improvements recommendation.
		Requirements Analysis and Design Definition	
		Requirements Life Cycle Management (from inception to retirement)	
		Solution Evaluation and improvements recommendation	
		EXTENSIBILITY Point:	TBD
	Business analysis and enterprise organisation	Agile Data Driven methodologies, processes and enterprises	Proposed new KA for DS-BoK General Business processes and operations KAs <ul style="list-style-type: none"> • Business processes and operations • Agile Data Driven methodologies, processes and enterprises • Use cases analysis: business and industry TBD further extensions
		Use cases analysis: business and industry	
		EXTENSIBILITY Point:	TBD

Appendix D. Example ECTS points assignment to different Data Science Professional groups

Table 13 Distribution of ECTS credit points between specific learning outcomes for profiles DSP01-03

LO ID	Data Science Competence	ECTS credit points by Knowledge levels.					
		Familiarity		Usage		Creation	
		BSc	MSc	BSc	MSc	BSc	MSc
Data Science Data Analytics							
LO1-DA	DSDA-DA - Use appropriate statistical techniques and predictive analytics on available data to deliver insights and discover new relations.				5		25
LO1.01	DSDA01 - Use predictive analytics to analyze big data and discover new relations.						
LO1.02	DSDA02 - Use appropriate statistical techniques on available data to deliver insights.				5		10
LO1.03	DSDA03 - Develop specialized analytics to enable agile decision making.						5
LO1.04	DSDA04 - Research and analyze complex data sets, combine different sources and types of data to improve analysis.						
LO1.05	DSDA05 - Use different data analytics platforms to process complex data.						5
LO1.06	DSDA06 - Visualise complex and variable data.						5
Data Science Data Management							
LO2-DM	DSDM-DM - Develop and implement data management strategy for data collection, storage, preservation, and availability for further processing.				15		15
LO2.01	DSDM01 - Develop and implement data strategy, in particular, in a form of Data Management Plan (DMP).				10		10
LO2.02	DSDM02 - Develop and implement relevant data models, including metadata.						
LO2.03	DSDM03 - Collect and integrate different data source and provide them for further analysis.						
LO2.04	DSDM04 - Develop and maintain a historical data repository of analysis results (data provenance).						
LO2.05	DSDM05 - Ensure data quality, accessibility, publications (data curation).						
LO2.06	DSDM06 - Manage IPR and ethical issues in data management.				5		5
Data Science Engineering							

LO ID	Data Science Competence	ECTS credit points by Knowledge levels.					
		Familiarity		Usage		Creation	
		BSc	MSc	BSc	MSc	BSc	MSc
LO3-ENG	DSENG-ENG - Use engineering principles to research, design, develop and implement new instruments and applications for data collection, analysis and management.				5		15
LO3.01	DSENG01 - Use engineering principles to research, design, prototype data analytics applications, or develop structures, instruments, machines, experiments, processes, systems.						
LO3.02	DSENG02 - Develop and apply computational solutions to domain related problems using wide range of data analytics platforms.						
LO3.03	DSENG03 - Develops specialized data analysis tools to support executive decision making.						5
LO3.04	DSENG04 - Design, build, operate database technologies.				5		
LO3.05	DSENG05 - Develop solutions for secure and reliable data access.						10
LO3.06	DSENG06 - Prototype new data analytics applications.						
Data Science Research Methods							
LO4-RM	DSRM-RM - Create new understandings and capabilities by using the scientific method (hypothesis, test/artefact, evaluation) or similar engineering methods to discover new approaches to create new knowledge and achieve research or organizational goals.				2		8
LO4.01	DSRM01 - Create new understandings and capabilities by using the scientific method (hypothesis, test, and evaluation) or similar engineering research and development methods.						
LO4.02	DSRM02 - Direct systematic study toward a fuller knowledge or understanding of the observable facts, and discovers new approaches to achieve research or organizational goals.						
LO4.03	DSRM03 - Undertakes creative work, making systematic use of investigation or experimentation, to discover or revise knowledge of reality, and uses this knowledge to devise new applications						2
LO4.04	DSRM04 - Ability to translate strategies into action plans and follow through to completion.				2		2
LO4.05	DSRM05 - Contribute to and influence the development of organizational objectives.						2

LO ID	Data Science Competence	ECTS credit points by Knowledge levels.					
		Familiarity		Usage		Creation	
		BSc	MSc	BSc	MSc	BSc	MSc
LO4.06	DSRM06 - Apply ingenuity to complex problems, develop innovative ideas						2
Business Process Management							
LO5-BPM	DSBPM-BPM - Use domain knowledge (scientific or business) to develop relevant data analytics applications, and adopt general Data Science methods to domain specific data types and presentations, data and process models, organisational roles and relations.				4		6
LO5.01	DSBPM01 - Understand business and provide insight, translate unstructured business problems into an abstract mathematical framework.						
LO5.02	DSBPM02 - Use data to improve existing services or develop new services.						
LO5.03	DSBPM03 - Participate strategically and tactically in financial decisions that impact management and organizations.				2		2
LO5.04	DSBPM04 - Provides scientific, technical, and analytic support services to other organizational roles.				2		2
LO5.05	DSBPM05 - Analyse customer data to identify/optimize customer relations actions.						2
LO5.06	DSBPM06 - Analyse multiple data sources for marketing purposes.						

Table 14 Distribution of ECTS credit points between specific learning outcomes for profiles DSP10-13

LO ID	Data Science Competence	ECTS credit points by Knowledge levels.					
		Familiarity		Usage		Creation	
		BSc	MSc	BSc	MSc	BSc	MSc
Data Science Data Analytics							
LO1-DA	DSDA-DA - Use appropriate statistical techniques and predictive analytics on available data to deliver insights and discover new relations.	25		5	20		
LO1.01	DSDA01 - Use predictive analytics to analyze big data and discover new relations.	5					
LO1.02	DSDA02 - Use appropriate statistical techniques on available data to deliver insights.	5					
LO1.03	DSDA03 - Develop specialized analytics to enable agile decision making.	5					
LO1.04	DSDA04 - Research and analyze complex data sets, combine different sources and types of data to improve analysis.	5		5	10		

LO ID	Data Science Competence	ECTS credit points by Knowledge levels.					
		Familiarity		Usage		Creation	
		BSc	MSc	BSc	MSc	BSc	MSc
LO1.05	DSDA05 - Use different data analytics platforms to process complex data.						
LO1.06	DSDA06 - Visualise complex and variable data.	5			10		
Data Science Data Management							
LO2-DM	DSDM-DM - Develop and implement data management strategy for data collection, storage, preservation, and availability for further processing.			10			10
LO2.01	DSDM01 - Develop and implement data strategy, in particular, in a form of Data Management Plan (DMP).			2			2
LO2.02	DSDM02 - Develop and implement relevant data models, including metadata.			2			2
LO2.03	DSDM03 - Collect and integrate different data source and provide them for further analysis.			2			2
LO2.04	DSDM04 - Develop and maintain a historical data repository of analysis results (data provenance).						
LO2.05	DSDM05 - Ensure data quality, accessibility, publications (data curation).			2			2
LO2.06	DSDM06 - Manage IPR and ethical issues in data management.			2			2
Data Science Engineering							
LO3-ENG	DSENG-ENG - Use engineering principles to research, design, develop and implement new instruments and applications for data collection, analysis and management.	25		25	20		10
LO3.01	DSENG01 - Use engineering principles to research, design, prototype data analytics applications, or develop structures, instruments, machines, experiments, processes, systems.	5		5	5		
LO3.02	DSENG02 - Develop and apply computational solutions to domain related problems using wide range of data analytics platforms.						
LO3.03	DSENG03 - Develops specialized data analysis tools to support executive decision making.						
LO3.04	DSENG04 - Design, build, operate database technologies.	10		10	5		
LO3.05	DSENG05 - Develop solutions for secure and reliable data access.	10		10	10		10
LO3.06	DSENG06 - Prototype new data analytics applications.						
Data Science Research Methods							

LO ID	Data Science Competence	ECTS credit points by Knowledge levels.					
		Familiarity		Usage		Creation	
		BSc	MSc	BSc	MSc	BSc	MSc
LO4-RM	DSRM-RM - Create new understandings and capabilities by using the scientific method (hypothesis, test/artefact, evaluation) or similar engineering methods to discover new approaches to create new knowledge and achieve research or organizational goals.	10	10				
LO4.01	DSRM01 - Create new understandings and capabilities by using the scientific method (hypothesis, test, and evaluation) or similar engineering research and development methods.	2	2				
LO4.02	DSRM02 - Direct systematic study toward a fuller knowledge or understanding of the observable facts, and discovers new approaches to achieve research or organizational goals.	2	2				
LO4.03	DSRM03 - Undertakes creative work, making systematic use of investigation or experimentation, to discover or revise knowledge of reality, and uses this knowledge to devise new applications	2	2				
LO4.04	DSRM04 - Ability to translate strategies into action plans and follow through to completion.	2	2				
LO4.05	DSRM05 - Contribute to and influence the development of organizational objectives.	2	2				
LO4.06	DSRM06 - Apply ingenuity to complex problems, develop innovative ideas						
Business Process Management							
LO5-BPM	DSBPM-BPM - Use domain knowledge (scientific or business) to develop relevant data analytics applications, and adopt general Data Science methods to domain specific data types and presentations, data and process models, organisational roles and relations.	10	10				
LO5.01	DSBPM01 - Understand business and provide insight, translate unstructured business problems into an abstract mathematical framework.	2	2				
LO5.02	DSBPM02 - Use data to improve existing services or develop new services.	2	2				
LO5.03	DSBPM03 - Participate strategically and tactically in financial decisions that impact management and organizations.						

LO ID	Data Science Competence	ECTS credit points by Knowledge levels.					
		Familiarity		Usage		Creation	
		BSc	MSc	BSc	MSc	BSc	MSc
LO5.04	DSBPM04 - Provides scientific, technical, and analytic support services to other organizational roles.	4	4				
LO5.05	DSBPM05 - Analyse customer data to identify/optimize customer relations actions.	2	2				
LO5.06	DSBPM06 - Analyse multiple data sources for marketing purposes.						

Table 15 Distribution of ECTS credit points between specific learning outcomes for profiles DSP14-16

LO ID	Data Science Competence	ECTS credit points by Knowledge levels.					
		Familiarity		Usage		Creation	
		BSc	MSc	BSc	MSc	BSc	MSc
Data Science Data Analytics							
LO1-DA	DSDA-DA - Use appropriate statistical techniques and predictive analytics on available data to deliver insights and discover new relations.	20		5	15		
LO1.01	DSDA01 - Use predictive analytics to analyze big data and discover new relations.	5					
LO1.02	DSDA02 - Use appropriate statistical techniques on available data to deliver insights.	5					
LO1.03	DSDA03 - Develop specialized analytics to enable agile decision making.						
LO1.04	DSDA04 - Research and analyze complex data sets, combine different sources and types of data to improve analysis.	5			10		
LO1.05	DSDA05 - Use different data analytics platforms to process complex data.	5		5	5		
LO1.06	DSDA06 - Visualise complex and variable data.						
Data Science Data Management							
LO2-DM	DSDM-DM - Develop and implement data management strategy for data collection, storage, preservation, and availability for further processing.			10			10
LO2.01	DSDM01 - Develop and implement data strategy, in particular, in a form of Data Management Plan (DMP).						
LO2.02	DSDM02 - Develop and implement relevant data models, including metadata.			2			2
LO2.03	DSDM03 - Collect and integrate different data source and provide them for further analysis.			2			2
LO2.04	DSDM04 - Develop and maintain a historical data repository of analysis results (data provenance).			4			4

LO ID	Data Science Competence	ECTS credit points by Knowledge levels.					
		Familiarity		Usage		Creation	
		BSc	MSc	BSc	MSc	BSc	MSc
LO2.05	DSDM05 - Ensure data quality, accessibility, publications (data curation).			2			2
LO2.06	DSDM06 - Manage IPR and ethical issues in data management.						
Data Science Engineering							
LO3-ENG	DSENG-ENG - Use engineering principles to research, design, develop and implement new instruments and applications for data collection, analysis and management.	70		45	75		
LO3.01	DSENG01 - Use engineering principles to research, design, prototype data analytics applications, or develop structures, instruments, machines, experiments, processes, systems.	10		5	10		
LO3.02	DSENG02 - Develop and apply computational solutions to domain related problems using wide range of data analytics platforms.	10		10	10		
LO3.03	DSENG03 - Develops specialized data analysis tools to support executive decision making.	10		5	10		
LO3.04	DSENG04 - Design, build, operate database technologies.	30		10	30		
LO3.05	DSENG05 - Develop solutions for secure and reliable data access.	5		5	5		
LO3.06	DSENG06 - Prototype new data analytics applications.	5		10	10		
Data Science Research Methods							
LO4-RM	DSRM-RM - Create new understandings and capabilities by using the scientific method (hypothesis, test/artefact, evaluation) or similar engineering methods to discover new approaches to create new knowledge and achieve research or organizational goals.	5			5		
LO4.01	DSRM01 - Create new understandings and capabilities by using the scientific method (hypothesis, test, and evaluation) or similar engineering research and development methods.	2			2		
LO4.02	DSRM02 - Direct systematic study toward a fuller knowledge or understanding of the observable facts, and discovers new approaches to achieve research or organizational goals.	2			2		
LO4.03	DSRM03 - Undertakes creative work, making systematic use of investigation or experimentation, to discover or revise knowledge of reality, and uses this knowledge to devise new applications						

LO ID	Data Science Competence	ECTS credit points by Knowledge levels.					
		Familiarity		Usage		Creation	
		BSc	MSc	BSc	MSc	BSc	MSc
LO4.04	DSRM04 - Ability to translate strategies into action plans and follow through to completion.	1			1		
LO4.05	DSRM05 - Contribute to and influence the development of organizational objectives.						
LO4.06	DSRM06 - Apply ingenuity to complex problems, develop innovative ideas						
Business Process Management							
LO5-BPM	DSBPM-BPM - Use domain knowledge (scientific or business) to develop relevant data analytics applications, and adopt general Data Science methods to domain specific data types and presentations, data and process models, organisational roles and relations.	5			5		
LO5.01	DSBPM01 - Understand business and provide insight, translate unstructured business problems into an abstract mathematical framework.	2			2		
LO5.02	DSBPM02 - Use data to improve existing services or develop new services.	1			1		
LO5.03	DSBPM03 - Participate strategically and tactically in financial decisions that impact management and organizations.						
LO5.04	DSBPM04 - Provides scientific, technical, and analytic support services to other organizational roles.	2			2		
LO5.05	DSBPM05 - Analyse customer data to identify/optimize customer relations actions.						
LO5.06	DSBPM06 - Analyse multiple data sources for marketing purposes.						

Table 16 Distribution of ECTS credit points between specific learning outcomes for profiles DSP17-19

LO ID	Data Science Competence	ECTS credit points by Knowledge levels.					
		Familiarity		Usage		Creation	
		BSc	MSc	BSc	MSc	BSc	MSc
Data Science Data Analytics							
LO1-DA	DSDA-DA - Use appropriate statistical techniques and predictive analytics on available data to deliver insights and discover new relations.	15					
LO1.01	DSDA01 - Use predictive analytics to analyze big data and discover new relations.	5					
LO1.02	DSDA02 - Use appropriate statistical techniques on available data to deliver insights.	2					
LO1.03	DSDA03 - Develop specialized analytics to enable agile decision making.						

LO ID	Data Science Competence	ECTS credit points by Knowledge levels.					
		Familiarity		Usage		Creation	
		BSc	MSc	BSc	MSc	BSc	MSc
LO1.04	DSDA04 - Research and analyze complex data sets, combine different sources and types of data to improve analysis.						
LO1.05	DSDA05 - Use different data analytics platforms to process complex data.	5					
LO1.06	DSDA06 - Visualise complex and variable data.	3					
Data Science Data Management							
LO2-DM	DSDM-DM - Develop and implement data management strategy for data collection, storage, preservation, and availability for further processing.			10			
LO2.01	DSDM01 - Develop and implement data strategy, in particular, in a form of Data Management Plan (DMP).						
LO2.02	DSDM02 - Develop and implement relevant data models, including metadata.			5			
LO2.03	DSDM03 - Collect and integrate different data source and provide them for further analysis.			5			
LO2.04	DSDM04 - Develop and maintain a historical data repository of analysis results (data provenance).						
LO2.05	DSDM05 - Ensure data quality, accessibility, publications (data curation).						
LO2.06	DSDM06 - Manage IPR and ethical issues in data management.						
Data Science Engineering							
LO3-ENG	DSENG-ENG - Use engineering principles to research, design, develop and implement new instruments and applications for data collection, analysis and management.	85		50			
LO3.01	DSENG01 - Use engineering principles to research, design, prototype data analytics applications, or develop structures, instruments, machines, experiments, processes, systems.	10		5			
LO3.02	DSENG02 - Develop and apply computational solutions to domain related problems using wide range of data analytics platforms.	10		10			
LO3.03	DSENG03 - Develops specialized data analysis tools to support executive decision making.	10		5			
LO3.04	DSENG04 - Design, build, operate database technologies.	40		15			
LO3.05	DSENG05 - Develop solutions for secure and reliable data access.	5		5			
LO3.06	DSENG06 - Prototype new data analytics applications.	5		10			
Data Science Research Methods							

LO ID	Data Science Competence	ECTS credit points by Knowledge levels.					
		Familiarity		Usage		Creation	
		BSc	MSc	BSc	MSc	BSc	MSc
LO4-RM	DSRM-RM - Create new understandings and capabilities by using the scientific method (hypothesis, test/artefact, evaluation) or similar engineering methods to discover new approaches to create new knowledge and achieve research or organizational goals.	5					
LO4.01	DSRM01 - Create new understandings and capabilities by using the scientific method (hypothesis, test, and evaluation) or similar engineering research and development methods.	2					
LO4.02	DSRM02 - Direct systematic study toward a fuller knowledge or understanding of the observable facts, and discovers new approaches to achieve research or organizational goals.	2					
LO4.03	DSRM03 - Undertakes creative work, making systematic use of investigation or experimentation, to discover or revise knowledge of reality, and uses this knowledge to devise new applications						
LO4.04	DSRM04 - Ability to translate strategies into action plans and follow through to completion.	1					
LO4.05	DSRM05 - Contribute to and influence the development of organizational objectives.						
LO4.06	DSRM06 - Apply ingenuity to complex problems, develop innovative ideas						
Business Process Management							
LO5-BPM	DSBPM-BPM - Use domain knowledge (scientific or business) to develop relevant data analytics applications, and adopt general Data Science methods to domain specific data types and presentations, data and process models, organisational roles and relations.	5					
LO5.01	DSBPM01 - Understand business and provide insight, translate unstructured business problems into an abstract mathematical framework.	2					
LO5.02	DSBPM02 - Use data to improve existing services or develop new services.	1					
LO5.03	DSBPM03 - Participate strategically and tactically in financial decisions that impact management and organizations.						

LO ID	Data Science Competence	ECTS credit points by Knowledge levels.					
		Familiarity		Usage		Creation	
		BSc	MSc	BSc	MSc	BSc	MSc
LO5.04	DSBPM04 - Provides scientific, technical, and analytic support services to other organizational roles.	2					
LO5.05	DSBPM05 - Analyse customer data to identify/optimize customer relations actions.						
LO5.06	DSBPM06 - Analyse multiple data sources for marketing purposes.						