EDISON Data Science Framework:
Part 2. Data Science Body of Knowledge (DS-BoK)
Release 2

Project acronym: EDISON
Project full title: Education for Data Intensive Science to Open New science frontiers
Grant agreement no.: 675419

Date	03 July 2017
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Version	Release 2, version 0.4
Dissemination level	PU
Status	Working document, request for comments
Document approved by	

Document Version Control			
Version	Date	Change Made (and if appropriate reason for change)	Initials of Commentator(s) or Author(s)
0.0	22/01/2016	Overview of existing BoKs related to Data Science	AM
0.1	18/03/2016	Updated version for ELG discussion	YD, AM, AB
0.2	4/07/2016	Updated version (after deliverable D2.2)	YD, TW
0.3	9/09/2016	Updated based on feedback from MC-DS implementation	YD
Release 1	10/10/2016	Release 1 after ELG03 meeting discussion	YD
Release 2, version 0.4	03/07/2017	Release 2 document (updated after multiple discussions and comments, ELG04 comments)	YD, AM

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Executive summary

The EDISON project is designed to create a foundation for establishing a new profession of Data Scientist for European research and industry. 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). This will provide a formal basis for Data Science professional certification, organizational and individual skills management and career transferability.

This document presents initial results of the Data Science Body of Knowledge (DS-BoK) definition that is linked to and based on the Data Science Competence Framework described in another document. The presented DS-BoK definition is based on overview and analysis of existing bodies of knowledge that are relevant to intended frameworks for Data Science and required to fulfil identified in CF-DS competences and skills.

The definition of the Data Science Body of Knowledge provides a basis for defining the Data Science Model Curriculum and further for the Data Science professional certification.

The presented DS-BoK defines six groups of knowledge areas groups (KGA) that are linked to the identified competence groups: KGA-DSA Data Analytics; KGA-DSDM Data Management, KGA-DSE Data Science Engineering, KGA-DSRM Research Methods; and KGA-DSBM Business Process Management. Defining the domain knowledge groups both for science and business will be a subject for further development in tight cooperation with the domain specialists.

The intended EDISON framework comprising of mentioned above components will provide a guidance and a basis for universities to define their Data Science curricula and courses selection, on one hand, and for companies to better define a set of required competences and skills for their specific industry domain in their search for Data Science talents, on the other hand.

Further work will be required to develop consistent DS-BoK that can be accepted by academic community and professional training community. The DS-BoK is presented to the academic and research community and will undergo wide community discussion via EDISON community forum and by presentation at community oriented workshops and conferences.

TABLE OF CONTENTS

1 Introduction

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The presented DS-BoK defines six groups of Knowledge Areas (KA) that are linked to the identified competence groups: KGA-DSA Data Analytics; KGA-DSDM Data Management, KGA-DSE Data Science Engineering, KGA-DSRM Research Methods; and KGA-DSBM Business Process Management. Defining the domain knowledge groups both for science and business will a subject for further development in tight cooperation with domain specialists.

The DS-BoK definition is based on the proposed CF-DS that defines the five groups of competences for Data Science that include the commonly recognised groups Data Analytics, Data Science Engineering, Domain Knowledge (as defined in the NIST definition of Data Science) and extends them with the two new groups *Data Management* and *Scientific Methods* (or Business Process management for business related occupations) that are recognised to be important for a successful work of Data Scientist but are not explicitly mentioned in existing frameworks.

Further work will be required to develop consistent DS-BoK that can be accepted 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 expects and practitioners. The DS-BoK will be presented to EDISON Liaison Group 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 coordinate 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, scientific methods, and business process management lifecycle models. Section 4 described the proposed DS-BoK structure and provides the initial definition of the DS-BoK. Section 5 provides summary of the achieved results and section 5 suggests questions for discussion to collects community feedback and experts opinion.

Appendices to this document contain important supplementary information: detailed information about reviewed bodies of knowledge related to identified Data Science knowledge areas; taxonomy of the Data Science knowledge areas and scientific disciplines built 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 Data Science Framework provides a basis for the definition of the Data Science profession and enabling the definition of the other components related to Data Science education, training, organisational roles definition and skills management, as well as professional certification.

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 [1]
- DS-BoK – Data Science Body of Knowledge [2]
- MC-DS – Data Science Model Curriculum [3]
- DSPP - Data Science Professional profiles and occupations taxonomy [4]
- Data Science Taxonomy and Scientific Disciplines Classification

The proposed framework provides basis for other components of the Data Science professional ecosystem such as

- EDISON Online Education Environment (EOEE)
- Education and Training Directory and Marketplace
- 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

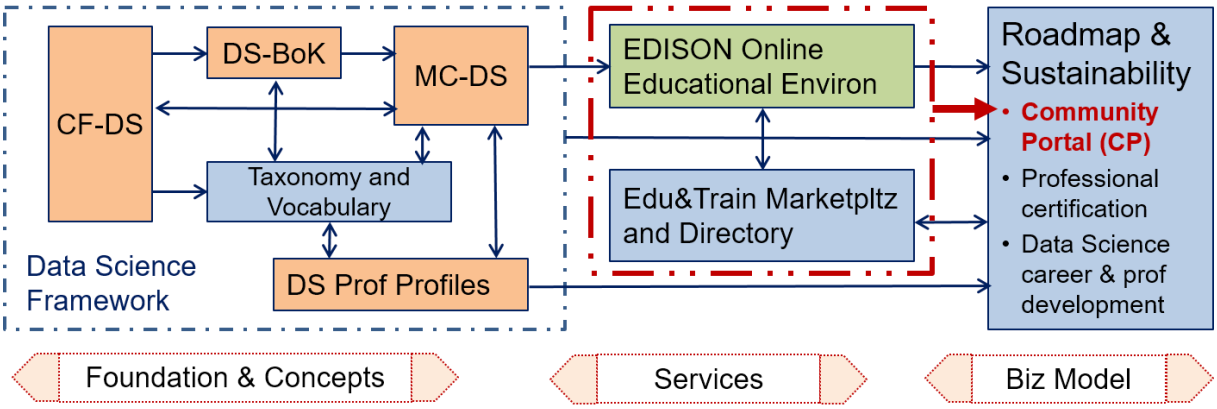

Figure 1 EDISON Data Science Framework components.

The CF-DS provides the overall basis for the whole framework, it first version has been published in November 2015 and was used as a foundation all following EDSF components developments. The CF-DS has been widely discussed at the numerous workshops, conferences and meetings, organised by the EDISON project and where the project partners contributed. The core CF-DS competences has been reviewed

The core CF-DS includes common competences required for successful work of Data Scientist 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 identified Data Science competences. DS-BoK is organised by Knowledge Area Groups (KAG) that correspond to the CF-DS competence groups. DS-BoK follows the same approach to collect community feedback and contribution: Open Access CC-BY community discussion document is published on the project website. 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 KA 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 proposed Learning outcomes are enumerated to have direct mapping to the enumerated competences in CF-DS. The preliminary version of MC-DS has been discussed at the first EDISON Champions Conference in June 2016 and collected feedback is incorporated in current version of MC-DS.

The DSPP are defined as an extension to European Skills, Competences, Qualifications and Occupations (ESCO) using the ESCO top classification groups. DSPP definition provides an important instrument to define effective organisational structures and roles related to Data Science positions and can be also used for building individual career path and corresponding competences and skills transferability between organisations and sectors.

The Data Science Taxonomy and Scientific Disciplines Classification will serve to maintain consistency between four core components of EDSF: CF-DS, DS-BoK, MC-DS, and DSP profiles. To ensure consistency and linking between EDSF components, all individual elements of the framework are enumerated, in particular: competences, skills, and knowledge subjects in CF-DS, knowledge groups, areas and units in DS-BoK, learning units in MC-DS, and professional profiles in DSPP.

It is anticipated that successful acceptance of the proposed EDSF and its core components will require standardisation and interaction with the European and international standardisation bodies and professional organisations. This work is being done as a part of the ongoing EDSF dissemination and sustainability activity.

The EDISON Data Science professional ecosystem illustrated in Figure 1 uses core EDSF components to specify the potential services that can be offered for professional Data Science community and provide basis for the sustainable Data Science and related general data skills sustainability. In particular, CF-DS and DS-BoK can be used for individual competences and knowledge benchmarking and play instrumental role in constructing personalised learning paths and professional (up/re-) skilling programs based on MC-DS.

3 Overview of BoKs relevant to DS-BoK

The following BoK's have been reviewed to provide a basis for initial definition of the DS-BoK:

- ACM Computer Science Body of Knowledge (ACM CS-BoK) [6, 7, 8]
- ICT professional Body of Knowledge (ICT-BoK) [9]
- Business Analytics Body of Knowledge (BABOK) [10]
- Software Engineering Body of Knowledge (SWEBOK) [11]
- Data Management Body of Knowledge (DM-BoK) by Data Management Association International (DAMAI) [12]
- Project Management Professional Body of Knowledge (PM-BoK) [13]

In the following sections we give a short description of each body of knowledge. The presented analysis provides a motivation that the intended/proposed DS-BoK should incorporate two dimensions in constructing DS-BoK: using Knowledge Areas (KA) and organisational workflow often linked to Project Phases (PP) or industry business process management (BPM). The DS-BoK should also reflect the data-lifecycle management[1]. Each process is defined as one or more activity, related knowledge and tools needed to execute it, inputs from other processes and expected output.

The presented analysis allowed to identify what existing BoK's can be used in the DS-BoK definition or mapped to ensure knowledge transferability and education programmes combination. From this initial analysis the relevant best practices have been identified to structure the DS-BoK and provide basis for defining the EDISON certification scheme and sustainability model.

3.1 ACM Computer Science Body of Knowledge (CS-BoK)

In the ACM-CS2013-final report [7, 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 distinguish between two type 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

[1] Such assumption has been also confirmed by user experience and expert interviews conducted in the project task T4.4.

programmes and specialisations. To be complete a curriculum should cover in addition to the topics of Core Tier 1 and 2 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 for computing Education in Community Colleges [9] 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 behaviour, and
(5) demonstrate business awareness and workplace effectiveness

The CS-BoK uses ACM Computing Classification System (CCS) which is standard and widely accepted what makes it a good basis for using it as a basis for building DS-BoK and providing necessary extensions/KAs related to identified Data Science competence groups (see section 3.4) which majority require background knowledge components from the general CS-BoK.

3.2 ICT professional Body of knowledge ICT-BoK

The ICT-BoK is an effort promoted by the European Commission, under the eSkills initiative (http://eskills4jobs.ec.europa.eu/) to defines and organises 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 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.

3.3 Software Engineering Body of Knowledge (SWEBOK)

The Software Engineering Body of Knowledge (SWEBOK) is an international standard ISO/IEC TR 19759:2015[2] specifying a guide to the generally accepted Software Engineering Body of Knowledge. The Guide to the Software Engineering Body of Knowledge (SWEBOK Guide) has been created through cooperation among several professional bodies and members of industry and is published by the IEEE Computer Society. The standard can be accessed freely from the IEEE Computer Society (http://www.computer.org/web/swebok/v3).[3]

[2] ISO/IEC TR 19759:2015 Software Engineering - Guide to the software engineering body of knowledge (SWEBOK)
[3] SWEBOK can be also accessed from http://www4.ncsu.edu/~tjmenzie/cs510/pdf/SWEBOKv3.pdf

The published version of SWEBOK V3 has the following 15 knowledge areas (KAs) within the field of software engineering: and 7 additional disciplines are recognized as linked and providing important background knowledge that are beneficial for Software engineering:

Table 4.1. SWEBOK Knowledge Areas and related disciplines

SWEBOK Knowledge Areas	Additional linked disciplines
• Software requirements • Software design • Software construction • Software testing • Software maintenance • Software configuration management • Software engineering management • Software engineering process • Software engineering models and methods • Software quality • Software engineering professional practice • Software engineering economics • Computing foundations • Mathematical foundations • Engineering foundations	• Computer engineering • Systems engineering • Project management • Quality management • General management • Computer science • Mathematics

3.4 Business Analysis Body of Knowledge (BABOK)

BABOK Guide was first published by International Institute of Business Analysis (IIBA) as a draft document version 1.4, in October 2005, for consultation with the wider business analysis and project management community, to document and standardize generally accepted business analysis practices. Current version 3 was released in April 2015.

The Business Analysis Body of Knowledge *provides interesting example of business oriented body of knowledge that covers important for Data Science knowledge domain. BABOK is published in a Guide to the Business Analysis Body of Knowledge* (*BABOK Guide*). It is the globally recognized standard for the practice of business analysis. *BABOK Guide* reflects the collective knowledge of the business analysis community and presents the most widely accepted business analysis practices.

BABOK Guide recognizes and reflects the fact that business analysis is continually evolving and is practiced in a wide variety of forms and contexts. It defines the skills, knowledge, and competencies required to perform business analysis effectively. It does not describe the processes that people will follow to do business analysis.

BABOK Guide includes chapters on:

- Business Analysis Key Concepts: define important terms that are the foundation of the practice of business analysis.
- Knowledge Areas: represents the core content of *BABOK Guide* and contain the business analysis tasks that are used to perform business analysis.
- Underlying Competencies: describes the behaviours, characteristics, knowledge, and personal qualities that help business analysts be effective in their job.
- Techniques: describes 50 of the most common techniques used by business analysts.
- Perspectives (new to version 3): describes 5 different views of business analysis (Agile, Business Intelligence, Information Technology, Business Architecture, and Business Process Management).

BABOK Guide organizes business analysis tasks within 6 knowledge areas. The knowledge areas logically organize tasks but do not specify a sequence, process, or methodology. Each task describes the typical

knowledge, skills, deliverables, and techniques that the business analyst requires to be able to perform those tasks competently.

The following knowledge areas of *BABOK Guid*e are defined:

- Business Analysis Planning and Monitoring: describes the tasks used to organize and coordinate business analysis efforts.
- Elicitation and Collaboration: describes the tasks used to prepare for and conduct elicitation activities and confirm the results.
- Requirements Life Cycle Management: describes the tasks used to manage and maintain requirements and design information from inception to retirement.
- Strategy Analysis: describes the tasks used to identify the business need, address that need, and align the change strategy within the enterprise.
- Requirements Analysis and Design Definition: describes the tasks used to organize requirements, specify and model requirements and designs, validate and verify information, identify solution options, and estimate the potential value that could be realized.
- Solution Evaluation: describes the tasks used to assess the performance of and value delivered by a solution and to recommend improvements on increasing value.

BABOK knowledge areas organisation by tasks allows easy linking to Business Analysis competences what can be implemented in the intended DS-BoK.

3.5 Data Management Body of Knowledge (DM-BoK) by DAMAI

The Data Management Association International (DAMAI) has been founded in 1988 in US with the aim: (i) to provide a non-profit, vendor-independent association where data professionals can go for help and assistance; (ii) to provide the best practice resources such as the DM-BoK and DM Dictionary of Terms; (iii) to create a trusted environment for DM professionals to collaborate and communicate.

The DM-BoK version2 “Guide for performing data management” is structured in 11 knowledge areas covering core areas in data management:

(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.

Each KA has *section topics* that logically group activities and is described by a *context diagram*. There is also an additional Data Management section containing topics that describe the knowledge requirements for data management professionals. Each context diagram includes: *Definition*, *Goals*, *Process*, *Inputs*, *Supplier roles*, *Responsible, Stakeholder, Tools*, *Deliverables*, *and Metrics* (See Appendix B).

When using DM-BoK for defining Data Management knowledge area for DS-BoK (DS-DM) it needs to be extended with the recent data modelling technologies and Big Data management platforms that address generic Big Data properties such as Volume, Veracity, Velocity. New data security and privacy protections need to be addressed as well (see CSA Top 10 Big Security challenges [14]).

3.6 Project Management Professional Body of knowledge (PM-BoK)

The PM-BoK is maintained by the Project Management Institute (PMI) the provides research and education services to Project Managers through publications, networking-opportunities in local chapters, hosting

conferences and training seminars, and providing accreditation in project management. PMI, exploit volunteers and sponsorships to expand project management's body of knowledge through research projects, symposiums and surveys, and shares it through publications, research conferences and working sessions. The “A Guide to the Project Management Body of Knowledge" (PM-BoK), has been recognized by the American National Standards Institute (ANSI) and in 2012 ISO adapted the project management processes from the PMBOK Guide 4th edition (see Appendix B).

The PMI-BoK defines five Process Groups related to project management:

- Initiating - Processes to define and authorize a project or project phase
- Planning - Processes to define the project scope, objectives and steps to achieve the required results.
- Executing - Processes to complete the work documented within the Project Management Plan.
- Monitoring and Controlling - Processes to track and review the project progress and performance. This group contains the Change Management.
- Closing - Processes to formalize the project or phase closure.

The nine Knowledge Areas are linked to the Process Groups:

- Project Integration Management - Processes to integrate various parts of the Project Management.
- Project Scope Management - Processes to ensure that all of the work required is completed for a successful Project and manages additional "scope creep".
- Project Time Management - Processes to ensure the project is completed in a timely manner.
- Project Cost Management - Processes to manage the planning, estimation, budgeting and management of costs for the duration of the project.
- Project Quality Management - Processes to plan, manage and control the quality and to provide assurance the quality standards are met.
- Project Human Resource Management - Processes to plan, acquire, develop and manage the project team.
- Project Communications Management - Processes to plan, manage, control, distribute and final disposal of project documentation and communication.
- Project Risk Management - Processes to identify, analyse and management of project risks.
- Project Procurement Management - Processes to manage the purchase or acquisition of products and service, or result to complete the project.
- Project Stakeholder Management – Process to identify stakeholders, determine their requirements, expectations and influence

Each Process Group contains processes within some or all of the Knowledge Areas. Each of the 42 processes has Inputs, Tools and Techniques, and Outputs. (It is not the scope of this analysis enter into the details of each process).

4 Data Science Body of Knowledge (DS-BoK) definition

This section presents summary of the Data Science Body of Knowledge definition given in separate DS-BoK document [2]. The presented DS-BoK definition is based on overview and analysis of existing bodies of knowledge that are relevant to Data Science and required to fulfil identified in CF-DS competences and skills.

The definition of the Data Science Body of Knowledge provides a basis for defining the Data Science Model Curriculum and further for the Data Science professional certification.

The presented DS-BoK defines five Knowledge Area Groups (KAG) that are linked to the identified competence groups: KGA1-DSDA Data Analytics; KGA2-DSENG Data Science Engineering, KGA3-DSDM Data Management, KGA4-DSRMP Research Methods and Project Management; and KGA5-DSBA Business Analytics that represents one of the most active domain area empowered by Data Science. Defining the domain knowledge groups KAG*-DSDK both for science and business will be a subject for further development in tight cooperation with the domain specialists.

4.1 General Approach and Structure of DS-BoK

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-DSRMP: *Research Methods and Project Management*
- KAG5-DSBA: Business Analytics
- KAG*-DSDK: Placeholder for the Data Science Domain Knowledge groups to include domain specific knowledge

The subject domain related knowledge group (scientific or business) KAG*-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 (as discussed in section 3.8.3) 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.

The proposed DS-BoK re-uses where possible or provides links to existing BoK's taking necessary KA definitions and combining them into defined above DS-BoK knowledge area groups. The following BoK's can be used or mapped to the selected DS-BoK knowledge groups:
ACM Computer Science CS-BoK [7, 8]
Business Analysis BABOK [10]
Software Engineering SWEBOK [11]
Data Management DMBOK by DAMA [12],
Project Management PM-BoK [13],
Classification Computer Science (CCS2012) [6] for Computer Science related knowledge areas.

4.2 Data Analytics Knowledge Area

Data Analytics includes different methods and algorithms, primarily statistical, to enable data processing, modelling, analysis and inspection with the goal of discovering useful information, providing insight and recommendations, and supporting decision-making. The following are commonly defined the Data Science Analytics Knowledge Areas:

- KA01.01 (DSDA.01/SMA) Statistical methods, including Descriptive statistics, exploratory data analysis (EDA) focused on discovering new features in the data, and confirmatory data analysis (CDA) dealing with validating formulated hypotheses;
- KA01.02 (DSDA.02/ML) Machine learning and related methods for information search, image recognition, decision support, classification;
- KA01.03 (DSDA.03/DM) *Data mining* is a particular data analysis technique that focuses on modelling and knowledge discovery for predictive rather than purely descriptive purposes;
- KA01.04 (DSDA.04/TDM) Text analytics applies statistical, linguistic, and structural techniques to extract and classify information from textual sources, a species of unstructured data;
- KA01.05 (DSDA.05/PA) Predictive analytics focuses on application of statistical models for predictive forecasting or classification.
- KA01.06 (DSDA.06/BA) Business Analytics and Business Intelligence covers data analysis that relies heavily on aggregation and different data sources and focusing on business information;
- KA01.07 (DSDA.07/MSO) Computational modelling, simulation and optimisation

4.3 DS-BoK Knowledge Area Groups

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-DSDA, KAG2-DSENG, KAG3-DSDM groups that are well supported by existing BoK's and academic materials. General suggestions are provided for KAG4-DSRMP, KAG5-DSBA 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-DSENG group includes selected KAs from ACM CS-BoK and SWEBOK 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.

Knowledge Units (KU) corresponding to suggested KAs are defined from different sources: existing BoK, CCS2012, and from practices in designing academic curricula and corresponding courses by universities and professional training organisations.

For the detailed definition of the KA and KU refer to the DS-BoK document [2]. The DS-BoK document contains detailed definition of the KAG1-DSA, KAG2-DSE, KAG3-DSDM, KAG4-DSRM, KAG5-DSBA 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.

Table 4.1. DS-BoK Knowledge Area Groups and corresponding Knowledge Areas

KA Groups	Suggested DS Knowledge Areas (KA)	Knowledge Areas from existing BoK and CCS2012 scientific subject groups
KAG1-DSDA: Data Science Analytics	KA01.01 (DSDA.01/SMDA) Statistical methods for data analysis KA01.02 (DSDA.02/ML) Machine Learning KA01.03 (DSDA.03/DM) Data Mining KA01.04 (DSDA.04/TDM) Text Data Mining KA01.05 (DSDA.05/PA) Predictive Analytics KA01.06 (DSDA.06/MODSIM) Computational modelling, simulation and optimisation	There is no formal BoK defined for Data Analytics. Data Science Analytics related scientific subjects from CCS2012: CCS2012: Computing methodologies CCS2012: Mathematics of computing CCS2012: Computing methodologies
KAG2-DSENG: Data Science Engineering	KA02.01 (DSENG.01/BDI) Big Data Infrastructure and Technologies KA02.02 (DSENG.02/DSIAPP) Infrastructure and platforms for Data Science applications KA02.03 (DSENG.03/CCT) Cloud Computing technologies for Big Data and Data Analytics KA02.04 (DSENG.04/SEC) Data and Applications security KA02.05 (DSENG.05/BDSE) Big Data systems organisation and engineering KA02.06 (DSENG.06/DSAPPD) Data Science (Big Data) applications design KA02.07 (DSENG.07/IS) Information systems (to support data driven decision making)	ACM CS-BoK selected KAs: AL - Algorithms and Complexity AR - Architecture and Organization (including computer architectures and network architectures) CN - Computational Science GV - Graphics and Visualization IM - Information Management PBD - Platform-based Development (new) SE - Software Engineering (can be extended with specific SWEBOK KAs) SWEBOK selected KAs • Software requirements • Software design • Software engineering process • Software engineering models and methods • Software quality Data Science Analytics related scientific subjects from CCS2012: CCS2012: Computer systems organization CCS2012: Information systems CCS2012: Software and its engineering
KAG3-DSDM: Data Management	KA03.01 (DSDM.01/DMORG) General principles and concepts in Data Management and organisation KA03.02 (DSDM.02/DMS) Data management systems KA03.03 (DSDM.03/EDMI) Data Management and Enterprise data infrastructure KA03.04 (DSDM.04/DGOV) Data Governance KA03.05 (DSDM.05/BDST0R) Big Data storage (large scale)	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.

KA Groups	Suggested DS Knowledge Areas (KA)	Knowledge Areas from existing BoK and CCS2012 scientific subject groups
	KA03.06 (DSDM.05/DLIB) Digital libraries and archives	Data Science Analytics related scientific subjects from CCS2012: CCS2012: Information systems
KAG4-DSRM: Research Methods and Project Management	KA04.01 (DSRMP.01/RM) Research Methods KA04.01 (DSRMP.02/PM) Project Management	There are no formally defined BoK for research methods PMI-BoK selected KAs • Project Integration Management • Project Scope Management • Project Quality • Project Risk Management
KAG5-DSBPM: Business Analytics	KA05.01 (DSBA.01/BAF) Business Analytics Foundation KA05.02 (DSBA.02/BAEM) Business Analytics organisation and enterprise management	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.

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

4.4 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 4.2 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 SWEBOK 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 4.2 Detailed definition of the DS-BoK and suggested Knowledge Units (KU)

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
KAG1-DSDA: Data Science Analytics	KA01.01 DSDA.01/SMDA Statistical methods for data analysis	KU1.01.01	Probability & Statistics	**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
		KU1.01.02	Statistical paradigms (regression, time series, dimensionality, clusters)	
		KU1.01.03	Probabilistic representations (causal networks, Bayesian analysis, Markov nets)	
		KU1.01.04	Frequentist and Bayesian statistics	
		KU1.01.05	Probabilistic reasoning	
		KU1.01.06	Exploratory and confirmatory data analysis	
		KU1.01.07	Quantitative analytics	
		KU1.01.08	Performance analysis	
		KU1.01.09	Markov models, Markov networks	
		KU1.01.10	Operations research	
		KU1.01.11	Information theory	
		KU1.01.12	Discrete Mathematics and Graph Theory	
		KU1.01.13	Mathematical analysis	
		KU1.01.14	Mathematical software and tools	
KAG1-DSDA: Data Science Analytics	KA01.02 DSDA.02/ML Machine Learning	KU1.02.01	Machine Learning theory and algorithms	**CCS2012: Computing methodologies** • Artificial intelligence ○ Machine learning ○ Learning paradigms ▪ Supervised learning ▪ Unsupervised learning ▪ Reinforcement learning ▪ Multi-task learning • Machine learning approaches ○ Machine learning algorithms
		KU1.02.02	Supervised Machine Learning	
		KU1.02.03	Unsupervised Machine Learning	
		KU1.02.04	Reinforced learning	
		KU1.02.05	Classification methods	
		KU1.02.06	Design and Analysis of Algorithms	
		KU1.02.07	Game Theory & Mechanism design	
		KU1.02.08	Artificial Intelligence	
		KU1.01.02	Statistical paradigms (regression, time series, dimensionality, clusters)	
		KU1.01.03	Probabilistic representations (causal networks, Bayesian analysis, Markov nets)	
		KU1.01.04	Frequentist and Bayesian statistics	**CCS2012: Theory of computation**
		KU1.01.05	Probabilistic reasoning	
		KU1.01.08	Performance analysis	

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
				• 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 • Semantics and reasoning
KAG1-DSDA: Data Science Analytics	KA01.03 DSDA.03/DM Data Mining	KU1.01.08	Performance analysis	**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 • Semantics and reasoning
		KU1.02.01	Machine Learning theory and algorithms	
		KU1.02.02	Supervised Machine Learning	
		KU1.02.03	Unsupervised Machine Learning	
		KU1.02.04	Reinforced learning	
		KU1.02.05	Classification methods	
		KU1.03.01	Data mining and knowledge discovery	
		KU1.03.02	Knowledge Representation and Reasoning	
		KU1.03.03	CRISP-DM and data mining stages	
		KU1.03.04	Anomaly Detection	
		KU1.03.05	Time series analysis	
		KU1.03.06	Feature selection, Apriori algorithm	
		KU1.03.07	Graph data analytics	
KAG1-DSDA: Data Science Analytics	KA01.04 DSDA.04/TDM Text Data Mining	KU1.04.01	Text analytics including statistical, linguistic, and structural techniques to analyse structured and unstructured data	**CCS2012: Computing methodologies** • Artificial intelligence ○ Natural language processing ○ Knowledge representation and reasoning ○ Search methodologies
		KU1.04.02	Data mining and text analytics	
		KU1.04.03	Natural Language Processing	
		KU1.04.04	Predictive Models for Text	
		KU1.04.05	Retrieval and Clustering of Documents	
		KU1.04.06	Information Extraction	
		KU1.04.07	Sentiments analysis	
	KA01.05 DSDA.05/PA	KU1.05.01	Predictive modeling and analytics	
		KU1.05.02	Inferential and predictive statistics	

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
KAG1-DSDA: Data Science Analytics	Predictive Analytics	KU1.05.03	Machine Learning for predictive analytics	
		KU1.05.04	Regression and Multi Analysis	
		KU1.05.05	Generalised linear models	
		KU1.05.06	Time series analysis and forecasting	
		KU1.05.07	Deploying and refining predictive models	
KAG1-DSDA: Data Science Analytics	KA01.06 DSDA.06/MODSIM Computational modelling, simulation and optimisation	KU1.06.01	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
		KU1.06.02	Operations research and optimisation	
		KU1.06.03	Large scale modelling and simulation systems	
		KU1.06.04	Network oprtimisation	
		KU1.06.05	Risk simulation and queueing	
KAG2-DSENG: Data Science Engineering	KA02.01 DSENG.01/BDI Big Data Infrastructure and Technologies	KU2.01.01	Computer systems organisation for Big Data applications, CAP, BASE and ACID theorems	**CCS2012: Computer systems organization** • Architectures ○ Parallel architectures ○ Distributed architectures • Networks *) ○ Network Architectures ○ Network Services ○ Cloud Computing
		KU2.01.02	Parallel and Distributed Computer Architecture	
		KU2.01.03	High Performance and Cloud Computing	
		KU2.01.04	Clouds and scalable computing	
		KU2.01.05	Cloud based Big Data platforms and services	
		KU2.01.06	Big Data (large scale) storage and filesystems (HDFS, Ceph, etc)	
		KU2.01.07	NoSQL databases	
		KU2.01.08	Computer networks for high-performance computing and Big Data infrastructure	
		KU2.01.09	Computer networks: architectures and protocols	
		KU2.01.10	Big Data Infrastructure management and operation	
KAG2-DSENG: Data	KA02.02 DSENG.02/DSIAPP	KU2.02.01	Big Data Infrastructure: services and components, including data storage infrastructure	• Proposed new KA for DS-BoK

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
Science Engineering	Infrastructure and platforms for Data Science applications	KU2.02.02	Big Data analytics platforms and tools (including Hadoop, Spark, and cloud based Big Data services)	• 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
		KU2.02.03	Large scale cloud based storage and data management	
		KU2.02.04	Cloud based applications and services operation and management	
		KU2.02.05	Big Data and cloud based systems design and development	
		KU2.02.06	Data processing models (batch, steaming, parallel)	
		KU2.02.07	Enterprise information systems	**CCS2012: Information systems** • Information storage systems • Information systems applications
		KU2.02.08	Data security and protection	
KAG2-DSENG: Data Science Engineering	KA02.03 DSENG.03/CCT Cloud Computing technologies for Big Data and Data Analytics	KU2.03.01	Cloud Computing architecture and services	**DSDA Extension group for CCS201** **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**
		KU2.03.02	Cloud Computing Engineering (infrastructure and services design, management and operation)	
		KU2.03.03	Cloud based applications and services operation and management	
KAG2-DSENG: Data Science Engineering	KA02.04 DSENG.04/SEC Data and Applications security	KU2.04.01	Infrastructure, applications and data security	
		KU2.04.02	Data encryption and key management, bockchain based technologies	
		KU2.04.03	Access Control and Identiy Management	
		KU2.04.04	Security services management, including compliance and certification	

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
		KU2.04.05	Data anonymisation	• DSA Extension point: Big Data systems (e.g. cloud based) **Information systems applications** • DSA Extension point: Big Data applications DSA Extension point: Doman specific Data applications
		KU2.04.06	Data privacy	
KAG2-DSENG: Data Science Engineering	KA02.05 DSENG.05/BDSE Big Data systems organisation and engineering	KU2.05.01	Big Data systems organisation and design	**CCS2012: Software and its engineering** • Software organization and properties ○ Software system structures • Software architectures ○ Software system models ○ Distributed systems organizing principles ▪ Cloud computing ▪ Grid computing • Software notations and tools ○ General programming languages ○ Software creation and management
		KU2.05.02	Big Data algorithms for large scale data processing	
		KU2.05.03	Big Data Analytics	
		KU2.05.04	Big Data analytics platforms and tools (including Hadoop, Spark, and cloud based Big Data services)	
		KU2.05.05	Big Data algorithms for data ingest, pre-processing, and visualisation	
		KU2.05.06	Big Data systems for application domains	
		KU2.05.07	Big Data software (systems) architectures	
		KU2.05.08	Requirements engineering and software systems development	
		KU2.05.09	Large and ultra-large scale software systems organisation	
		KU2.05.10	DevOps and cloud enabled applications development	
		KU2.05.11	Big Data Infrastructure management and operation	
KAG2-DSENG: Data Science Engineering	KA02.06 DSENG.06/DSAPPD Data Science (Big Data) applications design	KU2.06.01	Data analytics, data handling software requirements and design	**SWEBOK selected KAs** • Software requirements • Software design • Software construction • Software testing • Software maintenance
		KU2.06.02	Applications engineering management	
		KU2.06.03	Software engineering models and methods	
		KU2.06.04	Software quality assurance	
		KU2.06.05	Programming languages for Big Data analytics: R, python, Pig, Hive, others	

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
		KU2.06.06	Models and languages for complex interlinked data presentation and visualisation	• Software configuration 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
		KU2.06.07	Agile development methods, platforms and tools	
		KU2.06.08	DevOps and continuous deployment and improvement paradigm	

KAG2-DSENG: Data Science Engineering	KA02.07 DSENG.07/IS Information systems (to support data driven decision making)	KU2.07.01	Decision Analysis and Decision Support Systems	**CCS2012: Information systems**
				• Information systems applications
				  ○ Decision support systems
				  ▪ Data warehouses
				  ▪ Expert systems
				  ▪ Data analytics
				  ▪ Online analytical processing
				  ○ Multimedia information systems
				  ○ Data mining

		KU2.07.02	Predictive analytics and predictive forecasting	
		KU2.07.03	Data Analysis and statistics	
		KU2.07.04	Data warehousing and Data Mining	
		KU2.07.05	Data Mining	
		KU2.07.06	Multimedia information systems	
		KU2.07.07	Enterprise information systems	
		KU2.07.08	Collaborative and social computing systems and tools	

				CCS2012: Information systems
				• Information systems applications
				  ○ Enterprise information systems
				  ○ Collaborative and social computing systems and tools

KAG3-DSDM: Data Management	KA03.01 DSDM.01/DMORG General principles and concepts in	KU3.01.01	Data type registries, PID, metadata	**Proposed new KA for DS-BoK** General Data Management KA's
		KU3.01.02	Data Lifecycle Management	
		KU3.01.03	Data infrastructure and Data Factories	

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
	Data Management and organisation	KU3.01.04	Research data infrastructure, Open Science, Open Data, Open Access, ORCID	• Data Lifecycle Management • Data archives/storage compliance and certification
		KU3.01.05	Data infrastructure 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 • New KAs to follow RDA and ERA community developments
		KU3.01.06	Ethical principle and data privacy	
		KU3.01.07	FAIR (Findable, Accessible, Interoperable,) principles in Data Management	
KAG3-DSDM: Data Management	KA03.02 DSDM.02/DMS Data management systems	KU3.02.01	Data architectures (OLAP, OLTP, ETL)	**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 • CCS2012: Theory of computation ○ Database theory
		KU3.02.02	Data Modelling, Databases and Database Management Systems	
		KU3.02.03	Data structures	
		KU3.02.04	Data Models and Query Languages	
		KU3.02.05	Database design and models	
		KU3.02.06	Database administration	
		KU3.02.07	Data warehouses	
		KU3.02.08	Middleware for databases	
KAG3-DSDM: Data Management	KA03.03 DSDM.03/EDMI Data Management and Enterprise data infrastructure	KU3.03.01	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,
		KU3.03.02	Data Warehousing and Business Intelligence	
		KU3.03.03	Data storage and operations	
		KU3.03.04	Data archives/storage compliance and certification	
		KU3.03.05	Metadata, linked data, provenance	

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
		KU3.03.06	Data infrastructure, data registries and data factories	(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.
		KU3.03.07	Data security and protection	
		KU3.03.08	Data backup	
		KU3.03.09	Data anonymisation	
		KU3.03.10	Data Privacy	
KAG3-DSDM: Data Management	KA03.04 DSDM.04/DGOV Data Governance	KU3.04.01	Data governance, data quality, data Integration and Interoperability	DM-BoK (as above)
		KU3.04.02	Data Management Planning	
		KU3.04.03	Data Management Policy	
		KU3.04.04	Data interoperability	
		KU3.04.05	Data curation	
		KU3.04.06	Data provenance	
		KU3.04.07	Responsible data use, data privacy, ethical principles, IPR, legal issues	
KAG3-DSDM: Data Management	KA03.05 DSDM.05/BDST0R Big Data storage (large scale)	KU3.05.01	Big Data storage infrastructure and operations	New DSENG Knowledge area: Big Data Storage • Distributed file systems • Data Lakes • Data Factories
		KU3.05.02	Storage architectures, distributed files systems (HDFS, Ceph, Lustre, Gluster, etc)	
		KU3.05.03	Data storage redundancy and backup	
		KU3.05.04	Data factories, data pipelines	
		KU3.05.05	Cloud based storage, Data Lakes	
KAG3-DSDM: Data Management	KA03.06 DSDM.05/DLIB Digital libraries and archives	KU3.06.01	Digital libraries and archives organisation	**CCS2012: Information systems** • Information systems applications ○ Digital libraries and archives
		KU3.06.02	Information Retrieval	
		KU3.06.03	Data curation and provenance	
		KU3.06.04	Search Engines technologies	
KAG4-DSRMP: Research Methods and Project Management	KA04.01 DSRMP.01/RM Research Methods	KU4.01.01	Research methodology, paradigms and research cycle	**Proposed new KA for DS-BoK for DSRM related competences:** • Research methodology, research cycle (e.g. 4 steps model Hypothesis –
		KU4.01.02	Modelling and experiment planning	
		KU4.01.03	Data selection and quality evaluation	
		KU4.01.04	Data lifecycle	
		KU4.01.05	Use cases analysis: research infrastructures and projects	

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
		KU4.01.06	Research data management plan and ethical issues	Research Methods – Artefact – Validation) • Modelling and experiment planning • Data selection and quality evaluation • Use cases analysis: research infrastructures and projects
KAG4-DSRMPM: Research Methods and Project Management	KA04.01 DSRMP.02/PM Project Management	KU4.02.01	Project Integration Management	**PMI-BoK selected KAs** • Project Integration Management • Project Scope Management • Project Quality • Project Risk Management
		KU4.02.02	Project Scope Management	
		KU4.02.03	Project Quality	
		KU4.02.04	Project Risk Management	
KAG5-DSBPM: Business Analytics	KA05.01 DSBA.01/BAF Business Analytics Foundation	KU5.01.01	Business Analytics and Business Intelligence: Data, Models (statistical) and Decisions	**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.
		KU5.01.02	Data driven Customer Relations Management (CRP), User Experience (UX) requirements and design	
		KU5.01.03	Operations Analytics	
		KU5.01.04	Business Process Optimization	
		KU5.01.05	Data Warehouses technologies, data integration and analytics	
		KU5.01.06	Data driven marketing technologies	
		KU5.01.07	Business Analytics Capstone	
		KU5.01.08	Econometrics methods and application for Business Analytics	
		KU5.01.09	Cognitive technologies for Business Analytics	
KAG6-DSBA: Business Analytics	KA05.02 DSBA.02/BAEM Business Analytics organisation and enterprise management	KU5.02.01	Business processes and operations	**Proposed new KA/KU for DS-BoK** • General Business processes and operations KAs • Business processes and operations • Agile Data Driven methodologies, processes and enterprises
		KU5.02.02	Project scope and risk management	
		KU5.02.03	Business Analysis Planning and Monitoring	
		KU5.02.04	Requirements Analysis and Design Definition	
		KU5.02.05	Requirements Life Cycle Management (from inception to retirement)	

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
		KU5.02.06	Solution Evaluation and improvements recommendation	• Use cases analysis: business and industry
		KU5.02.07	Agile Data Driven methodologies, processes and enterprises	
		KU5.02.08	Use cases analysis: business and industry	

5 Conclusion and further developments

The presented work on defining the DS-BoK and other foundational components of the whole EDISON framework have been done with wide consultation and engagement of different stakeholders, primarily from research community and Research Infrastructures, but also involving industry experts via standardisation bodies, professional communities and directly via the project network.

5.1 Summary of findings

The provided document contains ongoing results of the Data Science Body of Knowledge definition that are based on the two other components Data Science Competence framework and Data Science knowledge area classification. In particular the DS-BoK uses the CF-DS competence and skills groups that include:

- Data Science Analytics (including Statistical Analysis, Machine Learning, Data Mining, Business Analytics, others)
- Data Science Engineering (including Software and Applications Engineering, Data Warehousing, Big Data Infrastructure and Tools)
- Domain Knowledge and Expertise (Subject/Scientific domain related)
- Data Management and Governance (including data stewardship, curation, and preservation)
- *Research Methods for research related professions and Business Process Management for business related professions*

Consequently, the CF-DS competence groups are presented in the DS-BoK 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-DSRMP: *Research Methods and Project Management*
- KAG5-DSBA: Business Analytics
- KAG*-DSDK: Placeholder for the Data Science Domain Knowledge groups to include domain specific knowledge

5.2 Further developments to formalize CF-DS and DS-BoK

It is anticipated that the presented ongoing development will require practical validation by experts and communities of practice that will include the following specific tasks and activities:

- Continue validating and improving the currently proposed knowledge areas and knowledge units 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 suggestions for new knowledge areas and classifications classes.
- Engage with the partner and champion universities into pilot implementation of DS-BoK and collecting feedback from practitioners.

Validation is an important part of the products that could be widely accepted by community. Validation of the proposed DS-BoK will be done in two main ways (similar to CF-DS). 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.

6 References

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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. Overview of Bodies of Knowledge relevant to Data Science

This section provides detailed information about existing Bodies of Knowledge relevant to the Data Science Body of Knowledge definition which can be linked to or mapped to the future DS-BoK.

A.1. ICT Professional Body of knowledge

Character	Explanation
Name of the Profession	ICT professional
Reference Community	(potentially) all ICT Professional
Leadership	Capgemini Consulting and Ernst & Young for the European Commission, Directorate General Internal Market, Industry, Entrepreneurship and SMEs
Organisation structure	N/A
Partners	N/A
Ethical Code	N/A
Estimated #members	N/A
Link to BoK	http://www.ictbok.eu/images/EU_Foundationa_ICTBOK_final.pdf
Year/Edition	2015/1st
Structure of BoK	There are 12 Knowledge Areas: ***1.*** ICT Strategy & Governance ***2.*** Business and Market of ICT ***3.*** Project Management ***4.*** Security Management ***5.*** Quality Management ***6.*** Architecture ***7.*** Data and Information Management ***8.*** Network and Systems Integration ***9.*** Software Design and Development ***10.*** Human Computer Interaction ***11.*** Testing ***12.*** Operations and Service Management Each Knowledge Area is defined by; • List of items required as foundational knowledge necessary under this Knowledge Area; • List of references to the e-Competence Framework (dimension 4: knowledge); • List of possible job profiles that require having an understanding of the Knowledge Area; • List of examples of specific Bodies of Knowledge, certification and training possibilities
Proposed use of BoK	• Education providers: as a source of inspiration for curricula design and development; • Professional Associations: to promote the Body of Knowledge to their members, ICT professionals; • HR Department and Managers within industry with a need to understand the range of knowledge and the entry level required by ICT professionals in order to improve recruiting and people development processes (together with skills and competencies).
Certification promoted	N/A

A.2. Data Management Professional Body of knowledge

Character	Explanation
Name of the Profession	Data Management Professional
Reference Community	Mainly US Data managers, professionals and scholars. Relevant chapters in UK and Australia.
Leadership	DAMAI a Volunteer US-based organization governed by an Executive Board of Directors. Directors are voted in for a 2 year term of office and may stand for re-election
Organisation structure	The members adhere through the nearest local chapter and through that (autonomous organisations affiliated with the central associations) participate to the life of the community
Partners	US-based organisation of medium relevance that provide educational resources (Dataversity, DEBtech, IRM UK, Technics Publications) or instruments and tools (VoltDB)
Ethical Code	Yes (available for members https://www.dama.org/content/chapter-kit-behind-login)
Estimated #members	Conferences are attended by a thousand people, 16 Chapters worldwide. No references about number of subscriptions
Link to BoK	BoK Framework • http://www.dama.org/sites/default/files/download/DAMA-DMBOK2-Framework-V2-20140317-FINAL.pdf DAMA International Guide to Data Management Body of Knowledge (on purchase) • https://technicspub.com/dmbok/ Other resources DAMA International Dictionary of Data Management Terms (on purchase) • https://technicspub.com/dmbok/
Edition/version	2012/v.2
Structure of BoK	The document is structured in 11 knowledge areas covering core areas in the DAMA - DMBOK2 Guide for performing data management. The 11 Data Management Knowledge Areas are: 1. **Data Governance** – planning, oversight, and control over management of data and the use of data and data-related resources. Governance covers 'processes', not 'things', hence the common term for Data Management Governance is Data Governance. 2. **Data Architecture** – the overall structure of data and data-related resources as an integral part of the enterprise architecture 3. **Data Modelling &Design** – analysis, design, building, testing, and maintenance (was Data Development in the DAMA - DMBOK 1st edition) 4. **Data Storage & Operations** – structured physical data assets storage deployment and management (was Data Operations in the DAMA-DMBOK 1st edition) 5. **Data Security** – ensuring privacy, confidentiality and appropriate access 6. **Data Integration & Interoperability** – acquisition, extraction, transformation, movement, delivery, replication, federation, virtualization and operational support (a Knowledge Area new in DMBOK2) 7. **Documents & Content** – storing, protecting, indexing, and enabling access to data found in unstructured sources (electronic files and physical records), and making this data available for integration and interoperability with structured (database) data.

	8. **Reference & Master Data** – Managing shared data to reduce redundancy and ensure better data quality through standardized definition and use of data values. 9. **Data Warehousing & Business Intelligence** – managing analytical data processing and enabling access to decision support data for reporting and analysis 10. **Metadata** – collecting, categorizing, maintaining, integrating, controlling , managing, and delivering metadata 11. **Data Quality** – defining, monitoring, maintaining data integrity, and improving data quality Each KA has section topics that logically group activities and it is described by a context diagram. There Is also an additional Data Management section containing topics that describe the knowledge requirements for data management professionals. Each context diagram includes: • *Definition*: a concise description of the Knowledge Area. • *Goals*: he desired outcomes of the Knowledge Area within this Topic. • *Process*: the list of discrete activities and sub-activities to be performed, with activity group indicators. • *Inputs*: what documents or raw materials are directly necessary for a Process to initiate or continue • *Supplier roles*: roles and/or teams that supply the inputs to the process. • *Responsible roles:* roles and/or teams that perform the process. • *Stakeholder roles*: roles and/or teams Informed or consulted on the process execution. • *Tools*: technology types used by the process to perform the function. • *Deliverables* : what is directly produced by the processes • *Consumer roles*: roles and/or teams that expect and receive the Deliverables. • *Metrics* : Measurements That quantify the success of Processes based on the Goals
Proposed use of BoK	• Informing a diverse audience about the nature and importance of data management. • Helping build consensus within the data management community. • Helping data stewards, data owners, and data professionals understand their responsibilities. • Providing the basis for assessments of data management effectiveness and maturity. • Guiding efforts to implement and improve data management knowledge areas. • Educating students, new hires, practitioners and executives on data management knowledge areas • Guiding the development and delivery of data management curriculum content for higher education. • Suggesting areas of further research in the field of data management. • Helping data management professionals prepare for Certified Data Management Professional (CDMP) data exams. • Assisting organizations in defining their enterprise data strategy.
Certification promoted	Certified Data Management Professional (CDMP) in four levels: • Associate (https://www.dama.org/content/cdmp-associate), • Practitioner (https://www.dama.org/content/cdmp-practitioner), • Master (https://www.dama.org/content/cdmp-master), • Fellow (https://www.dama.org/content/cdmp-fellow)

	Cost per exam: vary depending on the examination (from $220 of Associate till the 1560 for Master). Fellow is an assigned through nomination by peers and Chapter. Requirements: member of local chapter, sign/adhere to Ethical code/ proven experiences verifiable on the CV and contributions to the Association at various level

A.3. Project Management Professional Body of knowledge

Character	Explanation
Name of the Profession	Project Management Professional
Reference Community	Industry-centred worldwide Project Managers
Leadership	Project Management Institute – www.pmi.org PMI is a worldwide not-for-profit professional membership association for the project, program and portfolio management profession. Founded in 1969, PMI delivers advocacy, collaboration, education and research to its members.
Organisation structure	PMI is governed by a 15-member volunteer Board of Directors. Each year PMI members elect five directors to three-year terms. Three directors elected by others on the Board serve one-year terms as officers. Day-to-day PMI operations are guided by the Executive Management Group and professional staff at the Global Operations Centre located near Philadelphia. Each member adhere through the nearest local chapter and through that (autonomous organisations affiliated with the central associations) participate to the life of the community
Partners	No specific partnership but some 1600 Registered Education Providers (R.E.P.s) and about 100 certified courses worldwide (http://www.pmi.org/learning/professional-development/global-accreditation-center.aspx)
Ethical Code	Yes (http://www.pmi.org/About-Us/Ethics/Code-of-Ethics.aspx#)
Estimated #members	700.000 in 195 countries (source www.pmi.org) [Estimated some 2,9 acting PM worldwide and some 1,5 million PM posts till 2020]
Link to BoK	http://www.pmi.org/PMBOK-Guide-and-Standards/pmbok-guide.aspx (on purchase - $46,17) other resources • Lexicon of PM terms (http://www.pmi.org/PMBOK-Guide-and-Standards/PMI-lexicon.aspx - free for members) • PMBoK in other 11 languages (Arabian, Italian, Korean, Russian, Hindi, Japanese, Portuguese, Spanish, German, French, Chinese); • **Software Extension to the PMBOK** Guide Fifth Edition (This standard, developed by PMI jointly with IEEE Computer Society, provides guidance on the management of software development projects, and bridges the gap between the traditional, predictive approach described in the PMBOK® Guide and iterative approaches such as agile more commonly used in software development) (on purchase – $37,07) External sites: http://www.projectmanagement.com/Practices/PMI-Standards/
Year/Edition	2014/5th edition
Structure of BoK	The Five Process Groups *Initiating* - Processes to define and authorize a project or project phase

	Planning - Processes to define the project scope, objectives and steps to achieve the required results. *Executing* - Processes to complete the work documented within the Project Management Plan. *Monitoring and Controlling* - Processes to track and review the project progress and performance. This group contains the Change Management. *Closing* - Processes to formalize the project or phase closure. The Nine Knowledge Areas *Project Integration Management* - Processes to integrate various parts of the Project Management. *Project Scope Management* - Processes to ensure that all of the work required is completed for a successful Project and manages additional "scope creep". *Project Time Management* - Processes to ensure the project is completed in a timely manner. *Project Cost Management* - Processes to manage the planning, estimation, budgeting and management of costs for the duration of the project. *Project Quality Management* - Processes to plan, manage and control the quality and to provide assurance the quality standards are met. *Project Human Resource Management* - Processes to plan, acquire, develop and manage the project team. Project Communications Management - Processes to plan, manage, control, distribute and final disposal of project documentation and communication. *Project Risk Management* - Processes to identify, analyse and management of project risks. *Project Procurement Management* - Processes to manage the purchase or acquisition of products and service, or result to complete the project. Each Process Group contains processes within some or all of the Knowledge Areas. Each of the 42 processes has Inputs, Tools & Techniques and Outputs. (It is not the scope of this analysis enter into the details of each process).
Proposed use of BoK	It provides project managers with the fundamental practices needed to achieve organizational results and excellence in the practice of project management. It's a competence framework to support the PM practices. It's used also as "one of the books" to pass the examination.
Certification promoted	Several certification other than the basic about Project Management Professional in correspondence of specific roles that the PM may adopt in the carrier or depending on the type of project (http://www.pmi.org/certification.aspx): CAPM – Certified Associate Project Management PMP – Project Management Professional PgMP – Program Management Professional PfMP – Portfolio Management Professional PMI–PBA – PMI-Professional Business Analyst PMI-ACP – PMI Agile Certified Professional PMI-RMP – PMI Risk Management Professional PMI-SP – Scheduling Professional *Cost*: it may vary from the $225 of CAPM till the $900 for PgMP and PfMP of non-Members;

	Requirements: general Education (Secondary school or Degree) + Experience on the field of certification + specific Education on the field of certification.

Appendix B. Subset of ACM/IEEE CCS2012 for Data Science (as defined in DS-BoK Release 1)

This Appendix provides historical information about subset of the ACM/IEEE CCS2012 taxonomy used in the DS-BoK Release 1. This information is provided for those who build their Data Science curriculum definition on the previous DS-BoK version. The new DS-BoK Release 2 version has the whole set of the generically defined Knowledge areas and knowledge units that can be partly mapped to CCS2012 but primarily based on the knowledge subjects defined in CF-DS definition.

The defined below subset of ACM CCS (2012) classification can provide a basis for its future extension with a new classification group related to Data Science and individual disciplines that are missing in the current ACM/IEEE 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) [6] 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 DS-BoK Release 1, although compatible with DS-BoK Release 2:

- 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

Two other groups KAG4-DSRMP: Research Methods and Project Management 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 Release 1 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 1 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

DS-BoK Knowledge Groups *)	ACM (2012) Classification facets related to Data Science
	Data mining
Data Science Analytics (DSDA)	Theory of computation
	DSA Extension point: Algorithms for Big Data computation
	Mathematics of computing
EXTENSION POINT	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: Doman 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)	Information systems
	Data management systems
	Data types and structures description
EXTENSION POINT	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 **)
	Network Architectures
	Network Services
	Cloud Computing
Data Science Engineering (DSENG)	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
Data Science Engineering (DSENG)	Computing methodologies
	Modeling and simulation
	Model development and analysis
	Simulation theory
	Simulation types and techniques
	Simulation support systems
Data Science Engineering (DSENG)	Information systems
	Information storage systems
	Information systems applications
	Enterprise information systems

DS-BoK Knowledge Groups *)	ACM (2012) Classification facets related to Data Science
	Collaborative and social computing systems and tools
Data Science Engineering (DSENG)	Software and its engineering
	Software organization and properties
	DSE Extension point: Big Data applications design
EXTENSION POINT	Data Analytics programming languages
	Information systems
	DSE Extension point: Big Data and cloud based systems design
	Information systems applications
	DSA Extension point: Big Data applications
	DSA Extension point: Doman specific Data applications
DS Domain Knowledge (DSDK)	Applied computing
	Physical sciences and engineering
	Life and medical sciences
EXTENSION POINT	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 Competence Framework (CF-DS) Excerption

This Appendix contains excerption from the original CF-DS document [1] that is required for understanding of the presented in this document the DS-BoK. The excerption includes identified Data Science competences and corresponding knowledge units required to support those competences. The full CF-DS definition including both competences and skills is available in the CF-DS document.

C.1. Identified Data Science Competence Groups

The results of the job market study and analysis for Data Science and Data Science enabled vacancies, conducted at the initial stage of the project, provided a basis and justification for defining the main competence groups that are commonly required by companies, including identification such skills as Data Management and Research methods that were not required formerly required for data analytics jobs.

The following CF-DS competence and skills groups have been identified:

Core Data Science competences/skills groups defining profile of the Data Science related professional profiles

- Data Science Analytics (including Statistical Analysis, Machine Learning, Data Mining, Business Analytics, others)
- Data Science Engineering (including Software and Applications Engineering, Data Warehousing, Big Data Infrastructure and Tools)
- Domain Knowledge and Expertise (Subject/Scientific domain related)

Additional common competence groups demanded by organisations

- Data Management and Governance (including data stewardship, curation, and preservation)
- *Research Methods for research related professions and Business Process Management for business related professions*

Data management, curation and preservation competences are already attributed to the existing (research) data related professions such as data archivist, data manager, digital data librarian, and others. Data management is also important component of European Research Area and Open Data policies. It is extensively addressed by the Research Data Alliance and supported by numerous projects, initiatives and training programmes[4].

Knowledge of the scientific research methods and techniques is something that makes Data Scientist profession different from all previous professions.

From the education and training point of view, the identified competences can be treated or linked to expected learning or training outcome. This aspect is discussed in detail in relation to the definition of the Data Science Body of Knowledge and Data Science Model Curriculum.

The identified 5 Data Science related competence groups provide a better basis for defining consistent and balanced education and training programmes for Data Science related jobs, re-skilling and professional certification.

Table C.1 provides the proposed Data Science competences definition for different groups supported by the data extracted for the collected information. The presented competences definition has been reviewed by a number of expert groups and individual experts (see Section 7 for details). The presented competences are required for different professional profiles, organisational roles and throughout the whole data lifecycle, but not necessary to be provided y a single role or individuum. The presented competences are enumerated to allow easy use and linking between all EDSF document.

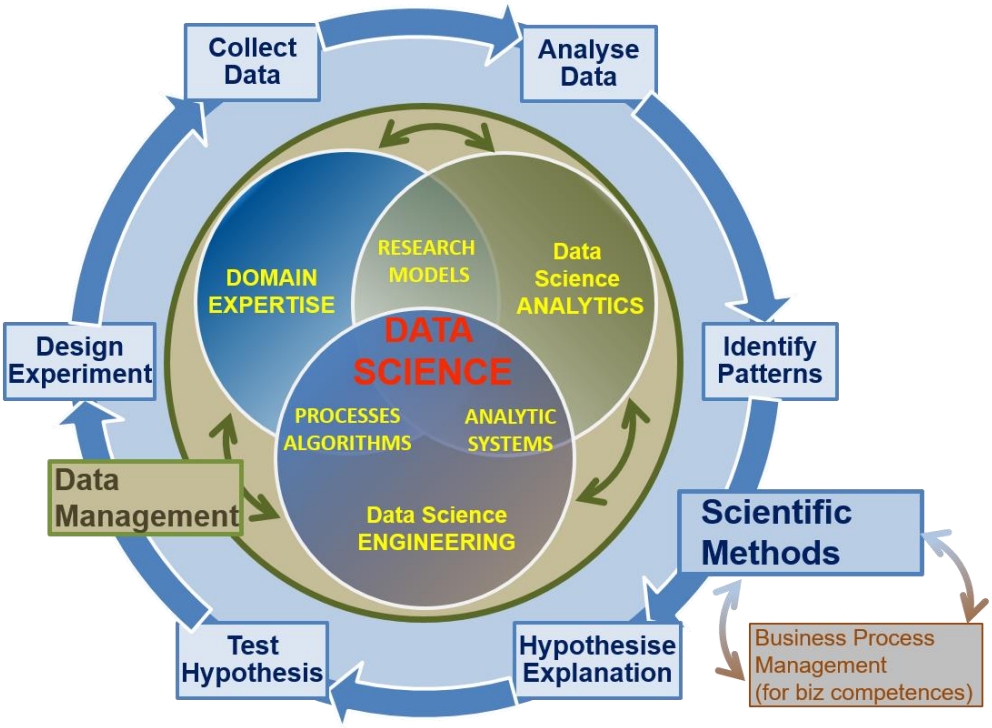
[4] Research Data Alliance Europe https://europe.rd-alliance.org/

Table C.1. Competences definition for different Data Science competence groups

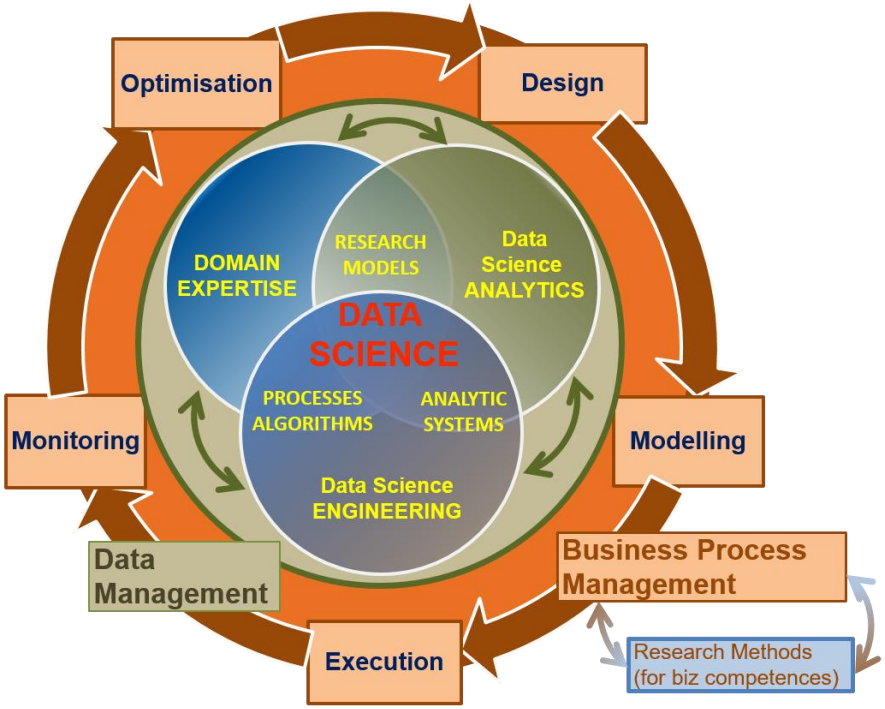
Data Analytics (DSDA)	Data Science Engineering (DSENG)	Data Management (DSDM)	Research Methods and Project Management (DSRM)	Domain related Competences (DSDK): Applied to Business Analytics (DSBA)
DSDA Use appropriate data analytics and statistical techniques on available data to discover new relations and deliver insights into research problem or organizational processes and support decision-making.	DSENG Use engineering principles and modern computer technologies to research, design, implement new data analytics applications; develop experiments, processes, instruments, systems, infrastructures to support data handling during the whole data lifecycle.	DSDM Develop and implement data management strategy for data collection, storage, preservation, and availability for further processing.	DSRM 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 organisational goals	DSDK Use domain knowledge (scientific or business) to develop relevant data analytics applications; adopt general Data Science methods to domain specific data types and presentations, data and process models, organisational roles and relations
DSDA01 Effectively use variety of data analytics techniques, such as Machine Learning (including supervised, unsupervised, semi-supervised learning), Data Mining, Prescriptive and Predictive Analytics, for complex data analysis through the whole data lifecycle	DSENG01 Use engineering principles (general and software) to research, design, develop and implement new instruments and applications for data collection, storage, analysis and visualisation	DSDM01 Develop and implement data strategy, in particular, in a form of data management policy and Data Management Plan (DMP)	DSRM01 Create new understandings by using the research methods (including hypothesis, artefact/experiment, evaluation) or similar engineering research and development methods	DSBA01 Analyse information needs, assess exisitng data and suggest/identify new data required for specific business context to achieve organizational goal, including using social network and open data sources
DSDA02 Apply designated quantitative techniques, including statistics, time series analysis, optimization, and simulation to deploy appropriate models for analysis and prediction	DSENG02 Develop and apply computational and data driven solutions to domain related problems using wide range of data analytics platforms, with the special focus on Big Data technologies for large datasets and cloud based data analytics platforms	DSDM02 Develop and implement relevant data models, define metadata using common standards and practices, for different data sources in variety of scientific and industry domains	DSRM02 Direct systematic study toward understanding of the observable facts, and discovers new approaches to achieve research or organisational goals	DSBA02 Operationalise fuzzy concepts to enable key performance indicators measurement to validate the business analysis, identify and assess potential challenges
DSDA03 Identify, extract, and pull together available and pertinent heterogeneous data, including modern data sources such as social media data, open data, governmental data	DSENG03 Develop and prototype specialised data analysis applicaions, tools and supporting infrastructures for data driven scientific, business or organisational workflow; use distributed, parallel, batch and streaming processing platforms, including online and cloud based solutions for on-demand provisioned and scalable services	DSDM03 Integrate heterogeneous data from multiple source and provide them for further analysis and use	DSRM03 Analyse domain related research process model, identify and analyse available data to identify research questions and/or organisational objectives and formulate sound hypothesis	DSBA03 Deliver business focused analysis using appropriate BA/BI methods and tools, identify business impact from trends; make business case as a result of organisational data analysis and identified trends

DSDA04 Understand and use different performance and accuracy metrics for model validation in analytics projects, hypothesis testing, and information retrieval	DSENG04 Develop, deploy and operate large scale data storage and processing solutions using different distributed and cloud based platforms for storing data (e.g. Data Lakes, Hadoop, Hbase, Cassandra, MongoDB, Accumulo, DynamoDB, others)	DSDM04 Maintain historical information on data handling, including reference to published data and corresponding data sources (data provenance)	DSRM04 Undertake creative work, making systematic use of investigation or experimentation, to discover or revise knowledge of reality, and uses this knowledge to devise new applications, contribute to the development of organizational objectives	DSBA04 Analyse opportunity and suggest use of historical data available at organisation for organizational processes optimization
DSDA05 Develop required data analytics for organizational tasks, integrate data analytics and processing applications into organization workflow and business processes to enable agile decision making	DSENG05 Consistently apply data security mechanisms and controls at each stage of the data processing, including data anonymisation, privacy and IPR protection.	DSDM05 Ensure data quality, accessibility, interoperability, compliance to standards, and publication (data curation)	DSRM05 Design experiments which include data collection (passive and active) for hypothesis testing and problem solving	DSBA05 Analyse customer relations data to optimise/improve interacting with the specific user groups or in the specific business sectors
DSDA06 Visualise results of data analysis, design dashboard and use storytelling methods	DSENG06 Design, build, operate relational and non-relational databases (SQL and NoSQL), integrate them with the modern Data Warehouse solutions, ensure effective ETL (Extract, Transform, Load), OLTP, OLAP processes for large datasets	DSDM06 Develop and manage/supervise policies on data protection, privacy, IPR and ethical issues in data management	DSRM06 Develop and guide data driven projects, including project planning, experiment design, data collection and handling	DSBA06 Analyse multiple data sources for marketing purposes; identify effective marketing actions

Figures C.1 (a) and (b) provide graphical presentation of relations between identified competence groups as linked to Scientific Methods or to Business Process Management. The figure illustrates importance of the Data Management competences and skills and Research Methods or Business Process Management knowledge for all categories and profiles of Data Scientists.



(a) Data Science competence groups for general or research oriented profiles.



(b) Data Science competence groups for business oriented profiles.

Figures C.1. Relations between identified Data Science competence groups for (a) general or research oriented and (b) business oriented professions/profiles: Data Management and Scientific/Research Methods or Business Processes Management competences and knowledge are important for all Data Science profiles.

The Research Methods typically include the following stages (see Appendix C for reference to existing Research Methods definitions):

- Design Experiment
- Collect Data
- Analyse Data
- Identify Patterns
- Hypothesise Explanation
- Test Hypothesis

Important part of the research process is the theory building but this activity is attributed to the domain or subject matter researcher. The Data Scientist (or related role) should be aware about domain related research methods and theory as a part of their domain related knowledge and team or workplace communications. See example of Data Science team building in the Data Science Professional Profiles definition provided as a separate document [4].

There is a number of the Business Process Operations models depending on their purpose but typically they contain the following stages that are generally similar to those for Scientific methods, in particular in collecting and processing data (see reference to exiting definitions (see Appendix C for reference to existing Business Process Management stages definitions):

- Design
- Model/Plan
- Deploy & Execute
- Monitor & Control
- Optimise & Re-design

The identified demand for general competences and knowledge on Data Management and Research Methods needs to be implemented in the future Data Science education and training programs, as well as to be included into re-skilling training programmes. It is important to mention that knowledge of Research Methods does not mean that all Data Scientists must be talented scientists; however, they need to know the general research methods such as formulating hypothesis, applying research methods, producing artefacts, and evaluating hypothesis (so called 4 steps model). Research Methods training are already included into master programs and graduate students of many master programs.

C.2. Knowledge required to support identified competences

Table C.2. Knowledge required to support identified competences

KDSDA Data Science Analytics	**KDSENG Data Science Engineering**	**KDSDM Data Management**	**KDSRM Research Methods and Project Management**	**KDSBA Business Analytics**
KDSDA01 Machine Learning (supervised): Decision trees, Naïve Bayes classification, Ordinary least square regression, Logistic regression, Neural Networks, SVM (Support Vector Machine), Ensemble methods, others	KDSENG01 Systems Engineering and Software Engineering principles, methods and models, distributed systems design and organisation	KDSDM01 Data management and enterprise data infrastructure, private and public data storage systems and services	KDSRM01 Research methods, research cycle, hypothesis definition and testing	KDSBA01 Business Analytics (BA) and Business Intelligence (BI); methods and data analysis; cognitive technologies

KDSDA02 Machine Learning (unsupervised): clustering algorithms, Principal Components Analysis (PCA), Singular Value Decomposition (SVD), Independent Components Analysis (ICA)	KDSENG02 Cloud Computing, cloud based services and cloud powered services design	KDSDM02 Data storage systems, data archive services, digital libraries, and their operational models	KDSRM02 Experiment design, modelling and planning	KDSBA02 Business Processes Management (BPM), general business processes and operations, organisational processes analysis/modelling
KDSDA03 Machine Learning (reinforced): Q-Learning, TD-Learning, Genetic Algorithms)	KDSENG03 Big Data technologies for large datasets processing: batch, parallel, streaming systems, in particular cloud based	KDSDM03 Data governance, data governance strategy, Data Management Plan (DMP)	KDSRM03 Data lifecycle and data collection, data quality evaluation	KDSBA03 Agile Data Driven methodologies, processes and enterprises
KDSDA04 Data Mining (Text mining, Anomaly detection, regression, time series, classification, feature selection, association, clustering)	KDSENG04 Applications software requirements and design, agile development technologies, DevOps and continuous improvement cycle	KDSDM04 Data Architecture, data types and data formats, data modeling and design, including related technologies (ETL, OLAP, OLTP, etc.)	KDSRM04 Use cases analysis: research infrastructure and projects	KDSBA04 Econometrics: data analysis and applications
KDSDA05 Text Data Mining: statistical methods, NLP, feature selection, apriori algorithm, etc.	KDSENG05' Systems and data security, data access, including data anonymisation, federated access control systems	KDSDM05 Data lifecycle and organisational workflow, data provenance and linked data	KDSRM05 Research Data Management Plan (DMP) and data stewardship	KDSBA05 Data driven Customer Relations Management (CRP), User Experience (UX) requirements and design
KDSDA06 Predictive Analytics	KDSENG06 Compliance based security models, privacy and IPR protection	KDSDM06 Data curation and data quality, data integration and interoperability	KDSRM06 Project management: scope, planning, assessment, quality and risk management, team management	KDSBA06 Use cases analysis: business and industry
KDSDA07 Prescriptive Analytics	KDSENG07 Relational, non-relational databases (SQL and NoSQL), Data Warehouse solutions, ETL (Extract, Transform, Load), OLTP, OLAP processes for large datasets	KDSDM07 Data protection, backup, privacy, IPR, ethics and responsible data use		KDSBA07 Data Warehouses technologies, data integration and analytics
KDSDA08 Graph Data Analytics: (path analysis, connectivity analysis, community analysis, centrality analysis, sub-graph isomorphism, etc.	KDSENG08 Big Data infrastructures, high-performance networks, infrastructure and services management and operation	KDSDM08 Metadata, PID, data registries, data factories, standards and com0liance		KDSBA08 Data driven marketing technologies
KDSDA09 Qualitative analytics	KDSENG09 Modeling and simulation, theory and systems	KDSDM09 Open Data, Open Science, research data archives/repositories, Open Access, ORCID		
KDSDA10 Natural language processing	KDSENG10 Information systems, collaborative systems			

KDSDA11 Data preparation and pre-processing				
KDSDA12 Performance and accuracy metrics				
KDSDA13 Operations Research				
KDSDA14 Optimisation				
KDSDA15 Simulation				

C.3. Identified Data Science Skills

For identified Data Science skills and technical platforms knowledge refer to the original CF-DS document [1].