Part V

IoT Skills and Business Models

17

The EU-IoT Skills Framework for IoT Training and Career Development Processes

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Abstract

This chapter sheds light on the ever-important issue of IoT skills development, which is a key prerequisite for the successful development, deployment, and operation of IoT systems. It first reviews the wide array of different IoT skills that are typically required for the development, deployment, and operation of nontrivial IoT systems, including technical and non-technical skills. Accordingly, it introduces the IoT skills framework of the H2020 EU-IoT project, which provides a taxonomy of modern IoT skills, along with an approach for defining skills profiles, as well as related educational activities and learning paths. It also leverages the results of a skills survey to identify popular and high in-demand skills profiles. Finally, it uses the introduced framework to drive the specification of practical learning paths for these profiles.

Keywords: Internet of Things, skills, education, skills framework, courses, training, human resources, future of work, technical skills, social skills, soft skills, management skills.

17.1 Introduction

Recent studies have concluded that IoT skills are a catalyst for the accelerated adoption of IoT solutions and for the subsequent growth of the IoT market. This is because the IoT skills shortage is identified as one of the factors that hinder IoT deployment [1]. Figure 17.1 illustrates some of the most important factors that lead to the proclaimed skills shortage. These factors include:

- **The multi-facet nature of IoT skills**: Nontrivial IoT solutions integrate multiple technology solutions such as embedded systems, broadband networks, cloud computing, machine learning, and cybersecurity. Therefore, most IoT professionals are required to possess multiple skills from different technological areas. Furthermore, many IoT skills profiles ask for non-technical skills like business development, marketing, and collaboration skills.
- **The complexity of IoT solutions**: In recent years, IoT solutions have become more sophisticated. State-of-the-art IoT solutions comprise multiple technology infrastructures, which have diverse development and deployment requirements. To deal with this complexity, IoT teams must comprise professionals with multi-disciplinary profiles and different skillsets. The latter go beyond the basics of IoT systems and technologies.
- **Technology acceleration**: Digital technologies are evolving at a rapid pace, which results in a fast-changing IoT landscape. For instance, technologies like mixed reality (MR) and augmented reality (AR) were not in the IoT landscape a few years ago. In this dynamic IoT landscape, it is very difficult for skills development activities to keep up with the evolution of the state-of-the-art.
- **The skills shortage in related technologies**: IoT projects require skills in cutting-edge technological areas like machine learning (ML), artificial intelligence (AI), and cybersecurity. Each of these technology areas is experiencing its own skills shortage, which makes it very difficult to staff complex IoT projects.
- **The need for collaboration in IoT projects**: Successful IoT deployments require collaboration between different stakeholders. This asks for interdisciplinary and multi-disciplinary expertise, which can be hardly found in modern IoT teams.

In this landscape, most organizations are faced with significant skills gaps, which asks for frequent reskilling processes. In a recent survey of the World Economic Forum (WEF) [2] the participating companies pointed out

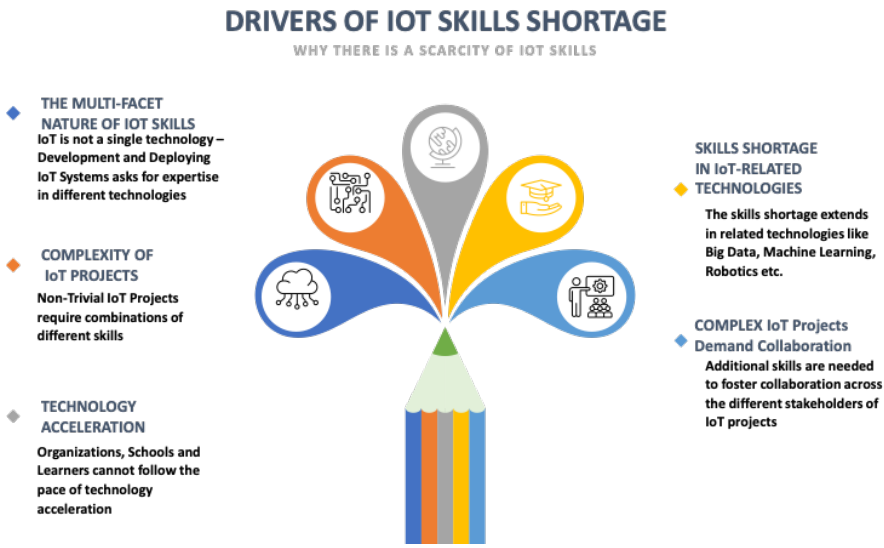

Figure 17.1 Factors contributing to the IoT skills shortage.

that they expected approximately 40% of their workers to undergo reskilling every six months. The same survey identifies the technical skills that are currently high in demand by companies, which include IoT. Moreover, the importance of non-technical skills like active learning and flexibility is stressed. Overall, employers acknowledge the need to intensify their investments in human skills development and are willing to undertake such investments. At the same time, policy makers are developing policies that foster digital skills development. For instance, the European Commission is currently implementing the ambitious European Skills Agenda [3], which is Europe's plan to help individuals and businesses to develop more and better skills. This skills agenda pays special emphasis on developing digital skills, including skills in areas like IoT, cloud computing, and AI.

To effectively plan their IoT upskilling and reskilling processes, organizations need to understand the various IoT skills and their interrelationships. Moreover, they must be able to map them to learning paths, training programs, and career development paths. This is also important for training and educating policy makers to develop effective reskilling and upskilling policies for both students and professionals. Therefore, there is a need for skills taxonomies that illustrate how diverse IoT skills are related to each, as well as how they can be bundled into coherent skills profiles.

In recent years, various educational organizations, consulting firms, and policy makers have identified skills that empower the development and operation of modern IoT systems. In several cases, they have also identified the interrelationships of these skills. Nevertheless, there is still a lack of an IoT skills framework that considers the latest developments in the IoT market and technologies. Considering this gap, this paper provides the following contributions:

- It introduces a novel framework for IoT skills, which considers recent advances in IoT technologies, as well as the need for complementing technical skills with social, business, and management skills. The framework has been developed in the scope of the EU-funded EU-IoT project, which provides resources and support services to the European IoT research community. It includes a taxonomy of IoT skills and can serve as a basis for defining skills profiles, education activities, and learning paths.
- It provides some concrete examples of IoT skills profiles, notably profiles that comprise skills that are high in demand in the IoT market. In this direction, the presented work leverages the results of an IoT skills survey that engaged over 100 professionals in the assessment of the relevant importance of various IoT skills. The survey was structured considering the introduced framework. Specifically, the participants were presented with lists of skills that were structured according to the framework.
- It illustrates some concrete examples of IoT skills profiles, along with learning paths that can be used to foster their development. Specifically, the suggested learning paths are associated with concrete courses in the training catalog of the EU-IoT project.

Note that the chapter consolidates and summarized findings that are already presented in the open-access whitepaper of the EU-IoT project [4]. These findings are included in this open-access book to boost the community's unlimited access to the EU-IoT project's results about IoT skills development.

The remainder of this chapter is structured as follows:

- Section 2, following this introductory section, provides an overview of research reports on IoT skills, including a review of relevant taxonomies. The section highlights the lack of a well-structured skills framework that considers the latest advances in IoT technologies.

- Section 3 introduces the EU-IoT skills framework as a multi-layer taxonomy. The framework considers the latest developments in IoT technologies, including developments in networking, IoT data analytics, machine learning IoT programming, and IoT security.
- Section 4 summarizes the results of a skills survey that was carried out with the active participation of more than 100 IoT professionals, who provided insights on the relevant importance of different IoT skills. A detailed presentation of the results of the survey is available in [4].
- Section 5 constructs some IoT profiles based on some skills that were identified as important in the skills survey. It also illustrates some indicative learning paths for the specified skills profiles.
- Section 6 is the final and concluding section of the chapter.

17.2 Related Work

IoT education and skills are catalysts for the adoption and growth of the IoT computing paradigm. At the same time, IoT skills are important for the development, deployment, and adoption of a range of related technologies such as AI and cyber physical production systems (CPPS). Moreover, industrial workers must develop IoT skills, to support the deployment and operation of Industrial IoT systems in their organizations in sectors like manufacturing, energy, oil and gas, mining, and healthcare. In general, IoT skills are important for most jobs and occupations of the future of work.

The future of work addresses a variety of industrial sectors, which require a broad range of IoT-related job profiles in various industries. Therefore, there is a need for identifying and properly structuring the various IoT skills in some IoT skills framework. To this end, many industrial, educational, and research actors have attempted to identify, document, and structure the rich set of modern IoT skills. The resulting classifications had different aims and objectives, such as employment, recruitment, education planning (e.g., [5]), curriculum development (e.g., [6]), industrial training (e.g., [7]), reskilling/upskilling, as well as policy development purposes [8] (e.g., industry/university collaboration [9]).

Several IoT skills reviews have focused on technical and technological skills. This is the case for reviews that aim at analyzing the technical skills required for developing and deploying IoT solutions. For instance, [10] outlines the importance of programming skills (e.g., Python, C, C#, Java Script) and knowledge of IoT protocols (e.g., Message Queuing Telemetry Transport (MQTT)) for IoT systems development and deployment. Furthermore,

there are articles that structure technical skills in integrated IoT profiles like hardware designers, embedded firmware developers, backend developers, frontend developers, IoT application developers, automation, and systems integration engineers, as well as data scientists [11]. These roles include profiles that are more general than the scope of IoT applications (e.g., frontend/backend developers). However, IoT technical jobs and IoT profiles go often beyond hardware and software development. Specifically, they cover roles like IoT engineers, IoT architects, and IoT researchers [12].

Nevertheless, taking a purely technical view of IoT skills is not enough. This is evident in policy-related studies (e.g., [13]), including the European Skills Agenda [3]. These studies underline the merits and importance of complementary skills such as soft skills. The latter are considered prerequisites both for building IoT and automation systems and for alleviating the adverse effects of automation in employment. Typical examples of soft skills include problem-solving, creativity, communication, and persuasion.

Due to the importance of non-technical skills, various IoT and Industrial Internet of Things (IIoT) skills surveys suggest that thinking, social, and other soft skills are critical elements of IoT education or reskilling for industry professionals [14]. For instance, [15] illustrates skills for managerial positions. The authors identify skills like problem-solving, IoT usage, analytical capabilities, communications, lifelong learning, management skills, teamwork, openness for change, openness to digitization, openness to automation, and more. Additional non-technical skills are mentioned in [14]. They include self-awareness, self-organization, interpersonal and intercultural skills, social responsibility and accountability, leadership skills, people management, emotional intelligence, negotiation skills, entrepreneurship, and adaptability.

The above-listed reports and surveys on IoT skills do not provide any structured taxonomy of IoT skills. Moreover, they do not refer to some of the most recent IoT technologies in areas like analytics, embedded systems, and IoT networking. This is a significant gap for stakeholders like human resources professionals and policy makers, who need to understand the importance and interrelationships of various IoT-related skills prior to developing effective training programs and policies.

17.3 The Eu-IoT Skills Framework

17.3.1 Main principles

The EU-IoT framework has been developed based on the following principles:

- **Support for technical and non-technical skills**. The framework addresses technical and technological IoT skills, but also soft skills that relate to IoT professionals' roles.
- **Consideration of standards-based IoT stacks in the classification of IoT technical skills**. The framework structures the various technical IoT skills in-line with layered taxonomies of IoT technologies, such as the layers of standards-based IoT stacks like the stack of the IICF (industrial internet connectivity framework).
- **Classification of non-technical skills**. The framework structures the complementary non-technical skills into various categories such as legal, business, marketing, and social skills.
- **Extensibility**. The framework provides a way for structuring the various IoT-related skills. Interested parties can extend the framework with more skills while retaining its core structure.

17.3.2 Top-level categorization of IoT skills

The framework classifies IoT-related skills into four broad categories, as illustrated in Figure 17.2 and further detailed below:

- **IoT technical and technological skills**: This category comprises skills related to IoT technologies, including skills required to develop, deploy, and operate IoT systems. It provides broad coverage of the rich set of technologies that are currently associated with IoT systems.
- **Management, marketing, and regulatory skills**: This category comprises marketing and management skills that fall in the realm of IoT product and service development. It also includes regulatory-related skills such as general data privacy regulation (GDPR)-related skills and ethics-related skills.
- **IoT end-users and operator 4.0 skills**: This category consists of skills required for using and operating IoT systems in various sectors of the economy with an emphasis on industrial sectors.
- **Social and soft skills**: This comprises soft skills that are important for the development, deployment, operation, and use of IoT systems. It includes popular skills like teamwork, lifelong learning, and collaboration, which have clear relevance to IoT professionals as well.

Each of the four skills categories comprises a rich set of IoT skills, which are structured in subcategories. The structuring of the various skills provides a sound basis for understanding the types of skills needed for successfully

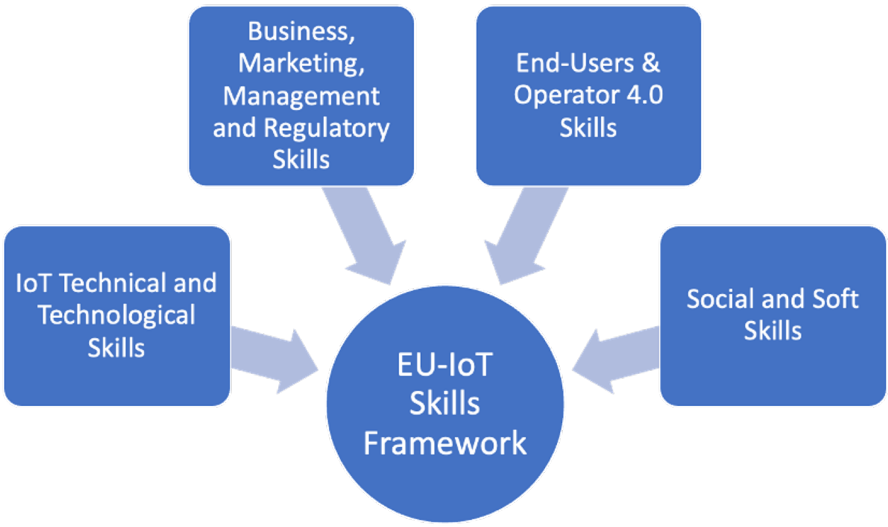

Figure 17.2 High-level taxonomy of the EU-IoT skills framework.

developing, deploying, operating, managing, and monetizing IoT systems. Hence, the various categories provide good coverage of the various types of IoT skills. Nevertheless, the listed skills provide by no means an exhaustive coverage of all the available IoT skills. As already outlined, interested parties can enhance the framework with more skills by expanding the list of skills that belong to the various (sub)categories.

17.3.3 The four categories of IoT skills

17.3.3.1 IoT technical and technological skills

The IoT technical and technological skills are further segmented into the following subcategories:

- **IoT devices skills**: This subcategory comprises skills associated with different types of internet-connected devices. Specifically, it includes skills associated with sensors, actuators, digital signal processing (DSP), field programmable gate arrays (FPGAs), the global positioning system (GPS), programmable logic controllers (PLC), wireless sensor networks (WSN), ad-hoc networks, radio frequency identification (RFID) devices and more. Each one of these skills corresponds to expertise regarding

the structure, the computational capabilities, and the networking functionalities of these IoT devices.

- **Smart objects skills**: This subcategory complements device-level skills with additional skillsets that correspond to more complex and sophisticated smart devices such as cyber-physical systems and unmanned aerial vehicles (UAVs). These sophisticated devices are characterized as smart objects. The sophistication of smart objects asks for special skills in developing, deploying, and operating them.
- **Networks and connectivity**: This part of the IoT technical and technological skills focuses on networking and connectivity technologies that support IoT deployments. Our list of skills in this subcategory includes popular networking protocols and connectivity technologies such as Wi-Fi, bluetooth, and low power wide area network (LPWAN) technologies. It also comprises mobile networking technologies like 4G, long-term evolution (LTE), 5G and 6G networking technologies.
- **IoT protocols**: This subcategory comprises skills associated with IoT connectivity protocols such as MQTT, constrained application protocol (CoAP), and data distribution service (DDS). These skills are essential to the development and deployment of IoT systems since they abstract the transport of IoT data from the device to the applications that consume the data.
- **Cloud/edge/mobile computing**: Cloud computing, edge computing, and mobile computing-related skills are important to the development, deployment, and operation of nontrivial IoT systems, such as systems that integrate data and services from multiple distributed IoT devices. Hence this subcategory is devoted to cloud/edge/mobile computing-related skills.
- **IoT analytics**: This subcategory comprises skills that enable the analysis of IoT data using various technologies and techniques such as ML, deep learning (DL), and AI. A wide array of such skills is nowadays important for IoT systems development and deployment ranging from big data analytics to embedded machine learning and TinyML.
- **IoT security**: Cybersecurity is a critical element of the safe and reliable deployment of IoT systems. Thus, there is a need for security-related IoT skills, such as skills relating to security processes (e.g., risk assessment, pen testing) and to the secure operation of various types of IoT devices.
- **IoT software programming skills**: Most IoT systems comprise software components. Therefore, software development skills are important

for the development of IoT systems and applications. This subcategory includes the rich set of programming skills that enable the development of the software parts of IoT systems. These skills include for example programming in popular languages like Python, Java and Javascript, as well as in other specialized skills for programming of IoT devices, for example, robotics programming and Arduino programming.

- **IoT development methodologies**: Many IoT products and services are developed and deployed over scalable, distributed infrastructure by distributed development teams. Therefore, the establishment of state-of-the-art development infrastructures and the employment of proper development methodologies over them is very important for the deployment and operation of successful IoT services. Hence, this subcategory includes skills associated with mainstream development infrastructures and methodologies that are commonly used by developers and deployers of IoT systems. These infrastructures and methodologies include for example development and operations (DevOps), data operations (DataOps), and machine learning operations (MLOps) infrastructures.
- **IoT development and deployment tools**: This subcategory includes skills linked to the operation and use of IoT development and deployment tools, such as integrated development environments (IDEs) for IoT development.

These subcategories establish a useful taxonomy of IoT-related technical and technological skills, which can be extended with more skills under the specified skills groupings. The specification of these subcategories was partly driven by popular reference architectures that specify the technical building blocks of modern IoT systems. For instance, the devices, networking technologies, and connectivity protocols are building blocks of IoT systems specified in the scope of the industrial internet reference architecture (IIRA) [16] and the industrial internet connectivity framework (IICF) [17] of the industrial internet consortium (IIC). Nevertheless, skills related to the technical building blocks identified in these reference architectures have been enhanced with skills pertaining to cloud infrastructures, software engineering, and project management methodologies. The latter is not specific to IoT systems only, but rather applicable to a broader range of future internet systems. These broader skills are important for the development, deployment, and operation of cutting-edge IoT systems, which is the reason why they have been included in the taxonomy.

17.3.3.2 Business, marketing, management, and regulatory skills

This category of the EU-IoT skills framework underlines the importance of marketing, management, and regulatory skills for tasks like IoT project management and IoT product development. The category comprises skills clustered in two subcategories, namely:

- **Business, management, and marketing skills**: This is a broad category that comprises various business, management, and marketing skills for IoT products and services. For instance, it includes project management, product management, marketing, and financial management skills.
- **Legal and regulatory skills**: This subcategory includes the ever-important legal and regulatory skills that are required for developing, deploying, and operating enterprise-scale IoT products and services with commercial relevance. Such products must adhere to applicable laws and regulations such as the general data protection regulation (GDPR) regarding data management and data protection. Therefore, the subcategory includes skills associated with IoT ethics, GDPR, and other IoT/AI-related regulations.

The list of skills in this category is purposefully shorter than the list of technical IoT skills. This reflects the fact that the development and deployment of IoT systems require primarily technical skills, yet business, management, and regulatory skills are important as well. Like in the case of other categories it is possible to extend the taxonomy with more skills of business, management, and regulatory relevance.

17.3.3.3 IoT end-user and operator 4.0 skills

This category includes skills that should be possessed by the end users of modern IoT systems. It includes the following subcategories of skills:

- **Industrial automation skills**: IIoT systems are usually deployed to support, improve, and enhance industrial automation processes in sectors like manufacturing, energy, oil & gas, and mining. Therefore, this subcategory is devoted to industrial automation skills that end-users of IoT systems must possess to successfully adopt, use, and fully leverage IoT functionalities. Such industrial automation skills include for example skills associated with the use of legacy automation systems and technologies (e.g., PLC and supervisory control and data acquisition (SCADA)), as well as with popular industrial processes like quality control and production scheduling. It also includes skills linked to emerging

digital tools for industrial automation like digital simulation and digital twins.

- **Asset management skills**: Asset management applications are found in almost all industrial sectors. They are deployed in all industries that manage physical assets such as in manufacturing, energy, and smart building applications. Therefore, end-users of IIoT applications for asset management must have relevant skills including asset programming, intelligent asset management, equipment maintenance, predictive maintenance, and more. The EU-IoT skills framework includes a special subcategory for these skills.
- **Visualization**: End-users of IIoT applications must understand and use visualizations of IoT data in industrial contexts. This subcategory is devoted to visualization skills, such as big data visualization, AR, MR, virtual reality (VR), and design of ergonomic user journeys.

Like in the case of the previous categories and subcategories, this list of identified skills for IoT end-users is representative rather than exhaustive. Interested parties (e.g., educators, human resources professionals, and policy makers) can extend the framework with more skills.

17.3.3.4 Social, management, and other soft skills

This category signifies the importance of soft skills for the development, deployment, and use of IoT systems. It comprises the following subcategories:

- **Thinking skills**, such as critical thinking, analytical thinking, and complex problem-solving.
- **Social skills**, such as teamwork, interpersonal skills, and professional ethics.
- **Personal skills**, such as lifelong learning, time management, people management, and emotional intelligence.

The relevance of soft skills for the development, deployment, and use of technology systems and applications goes beyond the scope of IoT systems and technologies. Their inclusion in the framework is aimed at ensuring that they are not ignored when developing or seeking for IoT talent.

17.3.4 Using the EU-IoT skills framework

17.3.4.1 End-user groups

The introduced framework is a useful tool for several stakeholder groups that engage in skills development processes, including:

- **IoT technology companies (e.g., IoT vendors and IoT solution integrators)**: These companies can use the framework as part of their hiring and skills development processes. It can serve as a guide for searching for the right talent, evaluating candidate workers based on their IoT knowledge and skills, as well as structuring training and skills development processes.
- **Users of IoT technology**: The framework can help companies that deploy and use IoT systems to properly shape the training and skills development processes of their digital transformation. The latter processes should put emphasis on developing or attracting professionals with the right IoT skills to ensure that their investments in IoT technology are effective and yield the best possible return on investment (ROI).
- **Policy makers**: Policy makers can consult our skills framework in the scope of their policy development processes, notably when developing educational and training policies. For example, they can use the framework to plan for training programs and effective educational policies that are relevant to modern IoT systems and address market needs.

17.3.4.2 Supporting training, hiring, and skills development processes

Some concrete examples of how to use the framework to support different types of training and skills development processes follow:

- **Training processes**: The framework can support the design and development of training programs that lead to the acquisition of certain key skills or even entire skills profiles. It can also help IoT professionals to select a portfolio of courses for developing or strengthening their IoT skills.
- **Hiring processes**: HR professionals can consult the framework when implementing hiring processes. Specifically, they can use it to identify the key skills required for specific positions. Moreover, it can help them cluster relevant skills and identify skills interrelationships. The latter is important when trying to hire or form a cohort of professionals that will staff some IoT-related department or project.
- **Skills development processes**: HR experts and individual IoT professionals can leverage the framework when designing skills development journeys. For instance, they can use it to cluster multiple related or complementary skills into skills profiles. Moreover, policy makers can

take advantage of the framework in their efforts to introduce new skills development programs that address proven skills gaps in the market.
- **Career development paths (CDP) specification**: Also, HR professionals can consult the framework when specifying and implementing CDPs for IoT roles. Specifically, the framework can help in the specification of meaningful CDPs, as well as their implementation through carefully selected collections of courses.

17.4 The Eu-IoT Skills Survey

17.4.1 Survey identity and methodological overview

In the scope of the H2020 EU-IoT project, we designed and executed an IoT skills survey that aimed at identifying the skills that are high in demand in the IoT market. The rationale behind the design and the implementation of the survey was to identify the IoT-related skills with the highest relevance in the IoT market. In this direction our methodology involved the following steps:

- **Designing the survey in-line with the EU-IoT framework**: The EU-IoT framework was used to structure questions about the IoT skills relevance and importance. Specifically, the survey was segmented into four subsurveys as per the four top-level skills categories of the EU-IoT framework. Hence, the four subsurveys concerned technical and technological skills, business and marketing skills, end-users, and operator 4.0 skills, as well as social and other soft skills. Each survey comprised lists of IoT-related skills. Participants were asked to grade the importance of each skill for the IoT market on a scale from 1 (very low) to 5 (very high). Hence, the importance of each skill was indicated by an importance score that was computed based on the total weighted average of the responses.
- **Collecting answers from relevant professionals**: IoT and HR professionals were invited to fill in the survey. The four different subsurveys were provided to different groups of relevant professionals with experience and expertise in IoT skills and IoT projects. For instance, the technical and technological skills subsurvey was answered by IoT professionals with relevant technical experience and expertise, as well as by HR professionals involved in IoT hiring processes. Likewise, the subsurvey on business, management, and marketing skills was answered by a different group that comprised professionals with expertise in IoT marketing and product management. Overall, as presented in Table 17.1, 70

Table 17.1 Number of respondents in the four subsurveys.

Subsurvey	Number of respondents
IoT technical and technological	70
Business, management, and marketing	37
End-users and operator 4.0 skills	40
Social and other soft skills	36

respondents answered the technical and technological skills subsurvey, 37 respondents answered the business and marketing skills subsurvey, 40 respondents answered the end-users and operator 4.0 skills subsurvey, and 36 respondents answered the social and other soft skills subsurvey. In total 183 respondents answered the four subsurveys. The participants come from different industries, including manufacturing, smart cities, energy, agriculture, and security. They also had various profiles and roles including project managers, technical project managers, engineers, data scientists, HR Professionals, developers, architects, researchers, product managers, and business development experts. All participants had jobs relevant to IoT and in most cases strong IoT knowledge and expertise.

- **Analyzing the results and identifying the most popular skills**: The results of each one of the subsurveys were analyzed to identify the popularity and importance of various IoT skills according to the opinions of the respondents. As already outlined, the relevant importance of each skill was ranked according to the weighted averages of the responses in the given scale. Skills falling within the same subcategory were directly comparable in terms of their importance and market relevance. For instance, the answers to the survey directly indicate the relevant importance of different device-level IoT skills and IoT analytics-related IoT skills. Skills falling in different subcategories of the same subsurvey (e.g., IoT networking vs. IoT devices skills) can only be indirectly compared.

17.4.2 Analysis of results and main findings

An exhaustive presentation of the results of the survey is beyond the scope of the book chapter. Interested readers are advised to consult [4], where the received responses and their analysis are described in detail. The following paragraphs illustrate and discuss the main findings of the analysis.

In general, the results of the survey indicate some of the most popular IoT skills according to the opinion of IoT professionals from different sectors.

The popularity of the skills is linked to the market demand for these skills, as the questions prompted the participants to rank the various skills according to their market demand and relevance.

17.4.2.1 Popularity of broadly applicable skills

One of the most prominent findings is that the most general and broadly applicable skills tend to be the most popular as well. The survey indicated that companies seek for professionals with a sound understanding of the basic skills due to their ubiquity and broad applicability. For instance, in machine learning and IoT analytics, the most fundamental skills (e.g., Big Data, ML, and Data Science) got higher ranks than more specialized and IoT-related analytics skills (e.g., TinyML) (see Figure 17.3). Similarly, as illustrated in Figure 17.4, MQTT skills were perceived as more important than other less general, sector-focused IoT protocols like OPC-UA which is primarily used in manufacturing and other industrial use cases.

Overall, the most popular skills were the ones that are broadly used in the scope of IoT systems and applications. This is because these skills enable professionals to engage in a wide range of IoT projects and activities.

17.4.2.2 Importance of specialized skills for sector-specific audiences

The survey unveiled that specialized skills are very important for specific segments and groups of IoT professionals. Specifically, the more specialized IoT

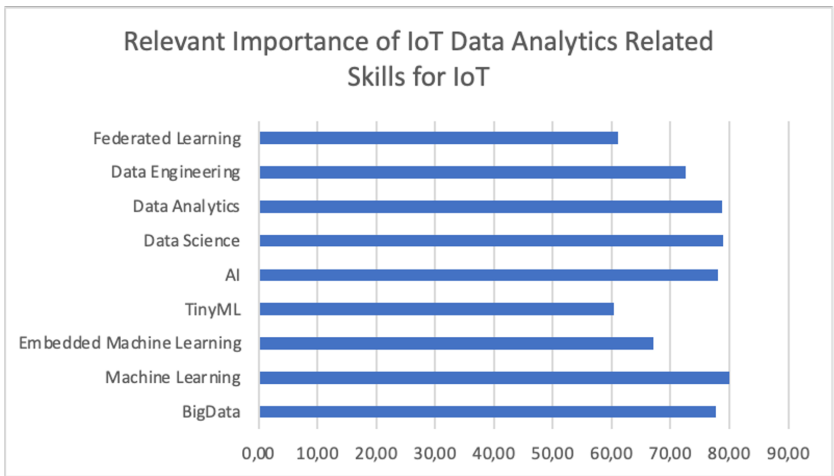

Figure 17.3 Relevant importance of IoT analytics-related skills.

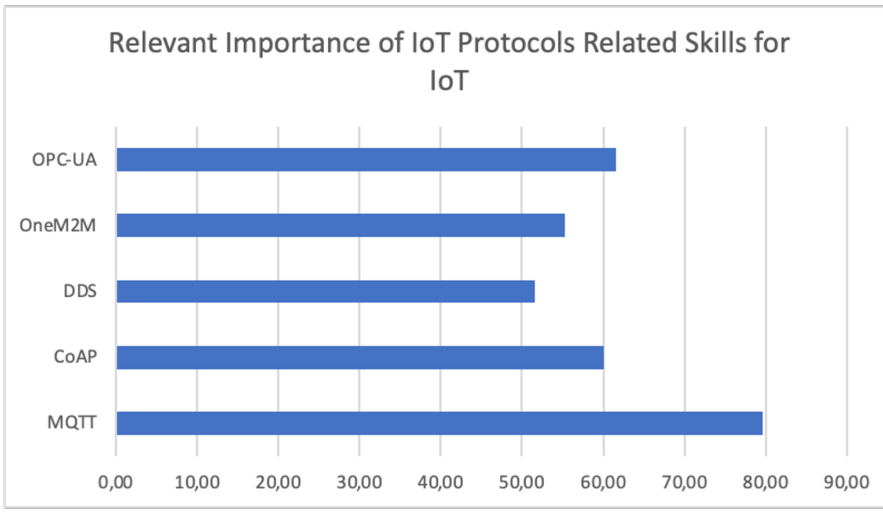

Figure 17.4 Relevant importance of IoT protocols-related skills.

skills are perceived as being very important for professionals within specific sectors. For instance, there are skills ranking very high within manufacturing (e.g., PLC and OPC-UA) and skills that rank very high within sectors that handle sensitive data (e.g., healthcare). This was evident in the segmentation of the responses according to the industry of focus of the respondents.

17.4.2.3 The importance of soft skills

Soft skills are a very important asset that complements IoT technical and technological skills. Several soft skills (e.g., lifelong learning skills) ranked very high in the overall standings of the skills that were included in the survey. Specifically, there are many skills that were graded over 70% (e.g., collaboration skills (Figure 17.5), time management skills, and people management skills) on the scale of the survey's importance. Successful IoT professionals cannot afford to ignore soft skills.

17.4.2.4 Skills clustering into skills profiles

The outcomes of the survey enable different approaches for clustering skills into skills profiles. Specifically, one can set criteria for the ranked skills to associate them with skills profiles. Such criteria may for example include the popularity of the skills and the need to combine skills from different (sub)categories of the framework. A set concrete and practical way to do this is presented in the following section.

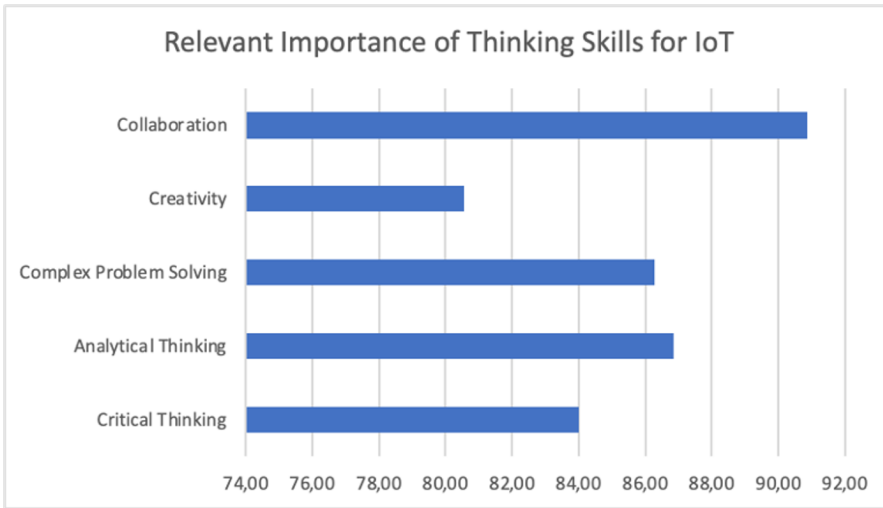

Figure 17.5 Relevant importance of different thinking skills.

17.5 From IoT Skills to Profiles and Learning Paths

17.5.1 Skills profiles and learning path construction methodology

To excel in the development, deployment, and operation of IoT systems and applications workers need more than IoT skills. For instance, IoT technical experts possess several of the previously presented skills from a single subcategory. As a prominent example, an IoT developer is likely to know more than one programming language to excel in the programming of the IoT Stack. However, it is also common for IoT professionals to possess technical skills from different subcategories of technical skills, such as programming skills and skills relating to IoT protocols like MQTT and CoAP. In most cases, IoT professionals match entire skills profiles that comprise multiple skills from different technological areas as well as non-technical skills (e.g., soft skills).

Clustering multiple IoT skills into skills profiles is very important for training and skills development processes. The latter is usually driven by the need to develop professionals that possess groups of relevant skills that enable them to undertake roles such as IoT software developer, IoT data engineer, IoT software engineer, IoT systems architect, embedded systems developer, and more. The EU-IoT skills framework can support the construction of skills profiles by facilitating interested stakeholders in selecting the skills to be clustered from a rich set of well-structured IoT skills. Using the framework

stakeholders can easily identify available skills and how they relate to each other. Hence, they can structure relevant skills profiles that meet the needs of their organizations. There is a variety of different skills profiles such as hardware designers, embedded firmware developments, IoT networking experts, IoT solution integrators, IoT applications frontend developers, IoT data scientists, IoT automation engineers, and many more.

A skills profile can drive the specification of learning pathways (i.e., collections of courses and other didactic activities) that lead to the acquisition of the skills of a profile. These learning pathways can form the basis of entire training programs at academic or professional levels. The simplest form of learning pathway specifications involves the structuring of a set of courses within a training program.

The H2020 EU-IoT project provides three powerful tools that facilitate the construction of skills profiles and learning paths:

- **The EU-IoT skills framework**, which facilitates the construction of coherent skills profiles that comprise well-structured and complementary collections of courses.
- **The EU-IoT survey [4]**, which can drive the specification of skills profiles subject to criteria like the overall popularity of certain skills, their relevance to specific industries (e.g., manufacturing), as well as their complementarity. For instance, the most popular IoT analytics-related technical skills can be used to form an IoT data scientist skills profile. As another example, a collection of popular methodologies (e.g., DevOps), tools (e.g., NodeRed), programming languages (e.g., Python), and devices (e.g., sensors, WSN) related skills can serve as the basis for the specification of an IoT developer profile.
- **The EU-IoT training catalog [18]**, which provides a pool of training resources that can be used to specify training programs that lead to the key skills of a given skills profile. Specifically, with a skills profile at hand, interested stakeholders can consult the IoT training resources catalog to identify a concrete set of available courses that can be structured in a learning pathway for the given skills profile.

17.5.2 Examples of IoT learning paths

The following tables provide six concrete examples of skills profiles, along with the skills they comprise. They also provide an indicative set of courses that can support the development of the proper skills for each profile. The listed courses can be found in the Udemy training ecosystem and the EU-IoT

Table 17.2 Skills and learning path for the "IoT application developer" skills profile.

IoT skills profile: IoT application developer
Individual skills of the profile: Python, JavaScript, IoT & Cloud Computing, DevOps, Docker, Kubernetes, Sensors, WSN, Arduino, MQTT
Courses of the main learning path: 1. Practical iot concepts-devices, IoT protocols and servers DevOps 2. Introduction to IoT programming with JavaScript 3. Exploring AWS IoT 4. Project – 2022: CI/CD with Jenkins Ansible Kubernetes 5. Arduino for beginners – 2022 complete course
Other relevant courses: 1. Collaboration and emotional intelligence 2. I.T. project management for beginners: a step-by-step guide

Table 17.3 Skills and learning path for the "IoT data analytics expert" skills profile.

IoT skills profile: IoT data analytics expert
Individual skills of the profile: Data science, machine learning, TinyML, sensors, WSN
Courses of the main learning path: 1. Master machine learning and data science with Python 2. Intro to embedded machine learning 3. Sensors/actuators/data visualization with microcontrollers – IoT dashboard with Arduino
Other relevant courses: 1. Statistics for data science and business analysis 2. Collaboration and emotional intelligence

Table 17.4 Skills and learning path for the "IoT networking engineer" skills profile.

IoT skills profile: IoT network engineer
Individual skills of the profile: Sensors and IoT Devices, LPWAN, 4G/5G/6G, WiFi, Bluetooth, MQTT
Courses of the main learning path: 1. Internet of things (IoT) – demystified using three IoT devices 2. 5G Masterclass: architecture, NR RAN, core, and call flows 3. The ultimate WLAN and WiFi training course 4. The complete bluetooth/IoT design course for iOS
Other relevant courses: 1. Collaboration and emotional intelligence 2. I.T. Project management for beginners: a step-by-step guide

training resources catalog. Specifically, each of the contents of the table presents the following information for each one of the six skills profiles:

- **Individual skills of the profile**: This is the list of skills that an IoT professional must possess to qualify for roles associated with the skills

Table 17.5 Skills and learning path for the "embedded systems engineer" skills profile.

IoT skills profile: embedded systems engineer
Individual skills of the profile: Embedded systems, FPGA, printed circuit board (PCB) design, sensors, actuators, WSN
Courses of the main learning path: 1. Mastering microcontroller and embedded driver development 2. Learn the fundamentals of VHDL and FPGA development 3. Sensors/actuators/data visualization with microcontrollers – IoT dashboard with Arduino 4. Crash course electronics and PCB design
Other relevant courses: 1. Arduino: electronics circuit, PCB Design & IoT programming 2. Collaboration and emotional intelligence

Table 17.6 Skills and learning path for the "IoT project manager" skills profile.

IoT skills profile: IoT project manager
Individual skills of the profile: Project management, sensors, WSN, DevOps, agile development
Courses of the main learning path: 1. I.T. project management for beginners: a step-by-step guide 2. Agile PM 301 – mastering agile project management 3. Project – 2022: CI/CD with Jenkins Ansible Kubernetes 4. Sensors/actuators/data visualization with microcontrollers – IoT dashboard with Arduino
Other relevant courses: 1. Presentation skills: master confident presentations 2. Management skills – team leadership skills masterclass 2022 3. Collaboration and emotional intelligence

profile. The presented lists are indicative. It is possible to broaden the scope of a skills profile by including additional skills in the list. As already outlined, the development of skills profile could consider the results of our survey toward including both relevant and popular skills in the profile.

- **Courses of the learning path**: This field includes a list of courses that can help professionals learn the listed skills. The tables include courses from the EU-IoT training catalog and the Udemy training ecosystem [19]. These courses are considered mandatory for acquiring the skills that are mandated by the skills profile. There is a variety of equivalent or similar courses in the training catalog and other ecosystems (e.g., Coursera and EdX) that could help build similar learning paths. In principle, the development of a proper learning path can be a challenging

Table 17.7 Skills and learning path for the "IoT product manager" skills profile.

IoT skills profile: IoT product manager
Individual skills of the profile: Product management, sensors, WSN, cyber-physical systems
Courses of the main learning path: 1. Agile PM 301 – mastering agile project management 2. Great product manager: product management by a big tech's PM 3. Complete guide to build IoT things from scratch to market 4. Sensors/actuators/data visualization with microcontrollers – IoT dashboard with Arduino
Other relevant courses: 1. Presentation skills: master confident presentations 2. Management skills – team leadership skills masterclass 2022 3. Advanced product management: vision, strategy, and metrics

process that should seek the optimal complementarity and compatibility of the selected courses.

- **Other relevant courses**: This field includes additional courses that could strengthen the learning path for the skills profile at hand. These courses could be considered optional or "nice to have" for the target profile. Like in the case of mandatory courses, the tables include courses from the EU-IoT training catalog and the Udemy training ecosystem. However, there is a variety of equivalent or similar courses in the training catalog and in other ecosystems (e.g., Coursera and EdX) that could help to provide an alternative collection of optional courses in order to strengthen the learning path.

Overall, the tables provide a set of representative examples that aim at illustrating the process of specifying learning paths based on available catalogs of training resources. There is however much room for interested stakeholders to fine-tune the learning paths development process by scrutinizing the vast amount of training resources that are available in existing course platforms.

17.6 Conclusions

Nowadays, there is a proclaimed gap in skills for automation and the future of work [20]. Closing this skills gap is very important for adopting and leveraging cutting-edge technologies of the fourth industrial revolution in many economic sectors [21]. IoT skills are among the most important elements of the skills puzzle, as IoT technologies have a broad scope and are widely used

in sectors like manufacturing, energy, healthcare, transport, retail, agriculture, and supply chain management [22]. State-of-the-art skills surveys identify some of the skills that are high in demand in the market. Nevertheless, they usually take a broad view that address many different digital technologies rather than focusing on the IoT skills and the IoT market. Motivated by this gap, this chapter has:

- Presented the findings of various skills surveys regarding the shortage of IoT skills.
- Introduced the EU-IoT skills framework as a structured taxonomy of IoT skills, including technical, management, and user-related skills, as well as the ever-important soft skills for IoT professionals. The framework can be extended with additional IoT skills.
- Summarized the findings of an IoT skills survey, which aimed at eliciting information about the IoT skills that are in the highest demand in the market.
- Illustrated how the skills survey and the EU-IoT framework can drive the clustering of individual IoT skills into wider IoT skills profiles.
- Provided concrete examples of learning paths for specific skills profiles based on courses and training resources of the EU-IoT training catalog [18].

Overall, this chapter has highlighted three tangible outcomes of the EU-IoT project (i.e., the skills framework, the survey, and the training resources catalog), which can be a great help to HR professionals and policy makers that plan, specify and execute skills development processes for the IoT computing paradigm.

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