Ontology Enhanced Representing and Reasoning of Job Specific Knowledge to Identify Skill Balance

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Abstract

The modernized and knowledge-based world of work (WoW) requires well-educated, skillful, and competent employees, who demonstrate the expected quality performance on the job. To supply knowledge, skills, and competences (KSCs) demanded by the WoW, vocational education and training (VET) systems are established. VET is understood as a demand-driven education sector in the world of education (WoE). On the premise that WoE supplies what is demanded by WoW, we may approach the problem of skill imbalance and mismatches not only on the micro level but also on the macro level.

The micro level matching determines whether a KSC possessed by a job seeker/an employee corresponds to KSCs required by an employer or if there is a KSC imbalance problem. The macro level skill matching is individual-independent i.e. between the learning outcomes of the learning fields supplied by the WoE and KSCs demanded by the WoW to perform the tasks of the job. The result of matching identifies to what extent the WoE can satisfy the demand of the WoW for qualified job applicants who possess the required KSCs. Consider the matching of the KSCs supplied by a learning field and the demanded KSCs for a job, the qualitative analysis results in five states: gap, shortage, surplus, obsolete and balance.

One way to reduce the skill imbalance is the (re)training of job-learners and/or on the job training of employees to develop or maintain the demanded KSCs. For this purpose and prior to initiating any training program, what is demanded to be learned should be identified. To do so, there is a need to establish a communication channel between WoW and WoE, which facilitates the detection of the imbalance between the supplied learning outcomes and demanded KSCs.

Taking the problem of supply-demand imbalance into account, the present thesis contributes in three dimensions. First, introducing and conceptualizing the communication channel and the matching space known as the world of competence (WoC). Second, semantic representation of the matching process by constituting the model of Job-Know Ontology, which provides a shared understanding and interpretation from the matching state. In order to assure the usability of the Job-Know Ontology especially for non-technical target groups in the WoW and WoE, developing the ontology shall confront a great challenge with regard to social quality and maturity. Third, formalizing and realizing the Job-Know Ontology, consisting of the two domains of WoW and WoE, as a generic solution not only to represent knowledge of the fields but also to support inferences and semantic reasoning (i.e. semantic matching of WoW and WoE).

In the light of this fact, the main result of the present thesis is an ontology called Job-Know Ontology as a representation of two interdisciplinary domains, WoW and WoE, to provide one picture by focusing on their melting point, which creates the WoC. The Job-Know Ontology provides novel mechanisms to infer the KSC states, which the labor market may confront, by matching the job tasks and the learning units of the field via supplied and demanded KSCs. Last but not least, the instantiation of the proposed model has been investigated and resulted in the development and evaluation of Nursing Job-Know Ontology. In addition, the degree of domain-independency of the proposed model has been examined through the realization of Production-Logistics Job-Know Ontology.

Zusammenfassung

Die modernisierte und wissensbasierte Welt der Arbeit (World of Work – WoW), benötigt gut ausgebildete, fähige und kompetente Arbeitnehmer, die die erwartete Leistung in ihrem Job erbringen. Um das Wissen, Können und die Kompetenz (Knowledge, Skills and Competences – KSCs), welche für die WoW verlangt werden, bereitzustellen, wurden berufsbildende Systeme (Vocational Edcuation and Training – VET) eingerichtet. VET wird als ein bedarfsgetriebener Bildungssektor in der Welt der Bildung (World of Education – WoE) verstanden. Basierend auf der Prämisse, dass die WoE bereitstellen soll, was von der WoW gefordert wird, können wir das Problem des Fähigkeiten-Ungleichgewichts und der Nichtübereinstimmung nicht nur auf einem Mikrolevel, sondern auch auf einem Makrolevel adressieren.

Das Mikrolevel "Matching" ermittelt, ob ein KSC, welches ein Job-Suchender oder ein Mitarbeiter besitzt, zu einem KSC passt, welches von einem Arbeitgeber benötigt wird oder ob es ein KSC-Ungleichgewichts-Problem gibt. Das Makrolevel Fähigkeiten-Matching ist personenunabhängig, z. B. zwischen Lernergebnissen der Lerngebiete, zur Verfügung gestellt durch die WoE, und den KSCs, nachgefragt durch die WoW, um jobbezogene Aufgaben zu erfüllen. Die Ergebnisse des Matchings identifizieren, zu welchem Grad die WoE den Bedarf der WoW an qualifizierten Bewerber decken kann, die die benötigten KSCs vorweisen. Unter Berücksichtigung des Matchings zwischen den angebotenen KSCs eines Lerngebiets und den benötigten KSCs für einen Job resultiert die qualitative Analyse in fünf Zuständen, nämlich lückenhaft, defizitär, überschüssig, obsolet und ausgeglichen (gap, shortage, surplus, obsolete and balance).

Ein Weg, das Fähigkeiten-Ungleichgewicht zu reduzieren, ist das (Um)trainieren von Job-Lernenden und/oder On-the-Job-Training von Mitarbeitern, um die benötigten KSCs zu erwerben oder zu erhalten. Für diesen Zweck und vor dem Initiieren eines Trainingsprogramms sollte identifiziert werden, was gelernt werden soll. Hierzu ist es notwendig, einen Kommunikationskanal zwischen der WoW und der WoE einzurichten, der ein Ungleichgewicht zwischen den angebotenen Lernzielen und den benötigten KSCs identifizieren kann.

Dem Problem des Ungleichgewichts zwischen Angebot und Bedarf Rechnung tragend, liefert diese Dissertation einen Beitrag in dreierlei Hinsicht. Erstens durch die Vorstellung und Konzeptualisierung des Kommunikationskanals und des Matching-Raums, bekannt als Welt der Kompetenz (World of Competence – WoC). Zweitens durch semantisches Repräsentieren des Matching-Prozesses durch die Entwicklung des Modells der Job-Know Ontologie, welches ein gemeinsames Verständnis und eine gemeinsame Interpretation aus dem Matching-Prozess

zur Verfügung stellt. Um die Anwendbarkeit der Job-Know-Ontologie insbesondere für nicht-technische Zielgruppen in der WoW und WoE sicherzustellen, stellt die Entwicklung der Ontologie eine große Herausforderung bezüglich der sozialen Qualität und des Reifegrades dar. Drittens durch Formalisieren und Realisieren der Job-Know-Ontologie, welche aus zwei Domänen besteht, der WoW und der WoE, als generische Lösung, um nicht nur das Wissen der Felder zu repräsentieren, sondern auch Inferenz und semantisches Ableiten zu unterstützen (z.B. semantisches Matching der WoW und WoE).

Vor diesem Hintergrund ist das Hauptresultat der vorgestellten Dissertation eine Ontologie, bezeichnet als Job-Know-Ontologie, als eine Repräsentation zweier interdisziplinären Domänen, WoW und WoE, um ein gemeinsames Bild durch Fokussieren auf deren Verbindungspunkt bereit zu stellen, der die WoC erzeugt. Die Job-Know-Ontologie stellt neue Mechanismen zur Verfügung, um KSC-Zustände abzuleiten (Fähigkeiten-(Un)gleichgewichtszustände), mit denen der Arbeitsmarkt konfrontiert sein kann, dadurch, dass die Arbeitsaufgaben und die Lerneinheiten des Gebietes durch die nachgefragten und angebotenen KSCs in Übereinstimmung gebracht werden. Schließlich wurde die Instantiierung des vorgeschlagenen Modells untersucht, woraus die Entwicklung und Evaluierung einer Pflege-Job-Know-Ontologie resultierte. Zusätzlich wurde der Grad der Domänenunabhängigkeit des vorgeschlagenen Modells untersucht, indem eine Produktionslogistik-Job-Know-Ontologie realisiert wurde.

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List of Abbreviations

Abbreviation	**Complete Term**
CEDFOP	European Centre for the Development of Vocational Training
EC	European Commission
EQF	European Qualification Framework
EU	European Union
ISCO	International Standard Classification of Occupations
ISCED	International Standard Classification of Education
KldB	Klassifikation der Berufe (in English: German Standard of Classification of Occupation)
KSC	Knowledge, Skills, and Competences
LF	Learning Field
LO	Learning Outcome
LU	Learning Unit
VET	Vocational Education and Training
WoC	World of Competence
WoE	World of Education
WoW	World of Work

1 Introduction

1.1 Context

Individuals as learners participate in the world of education (WoE), particularly vocational education and training (VET) to learn a specific job. VET provides learning units, which qualifies learners towards possessing knowledge, skills, and competences (KSCs) as the outcome of the learning process. KSCs enables learners to potentially become skillful employees and to perform specific jobs. In this way, WoE, particularly VET and not higher education (HE), should supply KSCs, qualifying the learners (potential employees) to perform the jobs defined by the world of work (WoW).

Individuals as employees are recruited to perform a specific job in the WoW. Jobs include a specific list of tasks and duties which are indicated and, in the ideal case, elaborated in the job's description. To perform a job, a list of KSCs, which should be identified in the job specification, are demanded. WoW, thereby, demands KSCs, which enable employees to perform their jobs and demonstrate expected quality.

Referring to the European Centre for the Development of Vocational Training (CEDEFOP's) European skills and jobs survey, one-fifth of European employees suffer skill gaps at recruitment, however, most develop the KSCs demanded by the employer on the job over time (Skills Panorama, 2016). Furthermore, 39% of European employees feel that they are overqualified to perform assigned job tasks (Skills Panorama, 2016). The survey results indicate that there is an imbalance between what is demanded by the WoW and what is supplied by the WoE in form of KSC.

The skill balance indicates how much WoE and WoW has a sustainable, updated, reliable, and mutual dialogue channel. If there is no dialogue channel to facilitate communication between WoE and WoW, or there is a failure in the dialogue channel, the WoW faces skill imbalance states: skills gap, shortage, surplus and/or obsolescence (Shah & Burke, 2003), (Cedefop, 2015). In consequence, the WoE is criticized by the WoW due to training learners who are incompetent to perform the jobs and unable to demonstrate expected (desired) quality. Thus, the training process should be repeated and will require resources and investment from the side of the WoW.

Skill imbalance can occur in different levels: organizational, regional, national, and international levels (e.g. European states). To tackle this problem, some solutions are discussed in the literature, such as i) increasing the working hours of employees who possess the demanded KSCs, ii) increasing the employees effort and efficiency by changing the incentive system, iii) (re)training job-learners and/or existing employees to possess the demanded KSCs, iv) match-making between learning outcomes supplied and KSCs demanded to perform a specific job (Shah & Burke, 2003) and (Cedefop, 2017).

KSCs are known as job specification in the WoW and learning outcome in the WoE. The World of Competence (WoC) is the introduced in this study as being the melting point of WoW and WoE (cf. Figure 1). The mutual relationship is, therefore, credited with a dialogue channel to tackle skill imbalance by (re)training the individuals (i.e. learner, employees) over time. On the one hand, the adjustment of the WoE based on the demands of WoW is slower than required. On the other, there is a serious lack of reliable and good quality information, which should be transferred to the WoE with adequate time to train skillful learners by the end of the learning process (ETF/Cedefop/ILO, 2017). Besides KSCs demanded by the WoW in current time, the new/emerging KSCs should be anticipated and defined earlier (in right time) (Cedefop 2016). WoE can, therefore, provide the demanded learning outcomes and can supply the right KSCs in right time. To keep the balance between the KSCs demanded by the WoW and the KSCs supplied by the WoE and to prevent gap, shortage, surplus and obsolesce in WoC, not only should the WoW report its demands to the WoE in adequate time, but the WoE should also act in a flexible and adjustable manner (i.e. in terms of speeding up to modify the content of lessons to train the potential employees in right time).

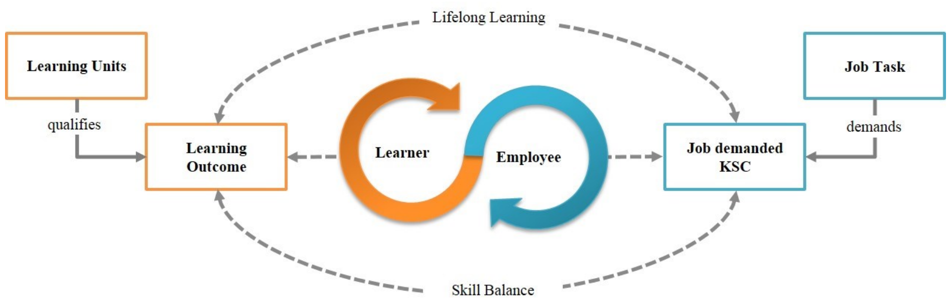

Figure 1 How WoE and WoW meet each other

According to the European Education and Training strategy (ET 2020), all individuals should be able to obtain, improve, and update the skills over time (European Union, 2009). Moreover, to respond to demands of an evolving knowledge-intense environment, all individuals should be given the equal chance to participate in (on-the-job or off-the-job) training and consequently possess new KSCs and/or improve their KSCs towards developing their careers over time (Cedefop, 2015). In the evolving knowledge-intensive environment, changing (e.g. improving didactic concepts or enhancing technological infrastructure) is continuously applied and ultimately triggers continuous learning. There are four types of lifelong learning opportunity, which include adult education, continuing education, professional development, and self-directed learning (WHO, 2010). One of the main advantages of the lifelong learning solution is facilitating inclusion of all interested individuals to learn what they want and need at their own pace, regardless of barriers like disabilities, distance, and gender (WHO, 2010).

1.2 Background

One of the main research topics of computer science is semantic modeling of knowledge-bases, which is done by knowledge representation tools and techniques (Marakas, 2016). Recent studies in different fields present ontologies that are widely considered to be an appropriate knowledge representation technology. Ontology, in computer science, is the specification of a shared conceptualization implemented in a machine readable format, which provides matching and reasoning opportunities (Neches, et al., 1991), (Gruber, 1993), (Guarino & Giaretta, 1995), (Studer, et al., 1998) and (Guarino, et al., 2009).

Ontologies, in general, provide benefits such as (Biesalski & Abecker, 2005) i) conceptualizing and structuring the domain of the interest from an abstract to a detail level in a taxonomy form, ii) reengineering the existing ontological and/ or non-ontological resources to create the best-fit ontology solution for a specific application or domain, iii) discarding, adding, editing the ontology concepts, relations and instances to maintain the knowledge-base and keep the ontology updated over time, iv) measuring similarities of the concepts, relations and instances of two (or even more) ontologies to support matching process, v) reasoning the complex axioms.

According to the literature on computer and data science, different methodologies[1] are established to develop an ontology, such as the methodology defined by Uschold and King in 1995 (Uschold & King, 1995), TOVE (Grüninger & Fox, 1995), METHONTOLOGY (Fernández-López, et al., 1997), HCOME (Kotis & Vouros, 2006), On-To-Knowledge (Sure, et al., 2009), UPON (Antonio, et al., 2009), DILIGENT (Pinto, et al., 2009), and NeOn (Suárez-Figueroa, et al., 2011), UPON- Lite (De Nicola & Missikoff, 2016).

As the ontology developed by the author is a domain-independent ontology, our approach was first to develop the T-Box of the ontology and then to instantiate it based on the individuals of the selected job and education domains to create the A-Box. Since none of the methodologies was able to completely fit our need (i.e. developing T-Box and A-Box separately), we established our own methodology (cf. Chapter 3.6). To develop the T-Box, define the concepts

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[1] The author has summarized the aforementioned methodologies in Appendix 1 (cf. Chapter 11.1) and discussed them in Chapter 2.3.2.

and roles as meta-model and then conceptualize them at detail level (cf. Chapter 3.6, where the development of the plans is further defined).

Considering the scope of the present thesis, some domain specific ontologies are categorized into two groups[2]: i) competence development (CD) ontologies, and ii) educational ontologies. Examples of CD ontologies include an ontology model for competence management to identify professional profile, the competence, and the context (Miranda, et al., 2017); the skill ontology according to activity assignment and human resource recruitment proposed by (Fazel-Zarandi & Fox, 2012); or the professional learning ontology which represents a common understanding of competence management from the resource-oriented perspective, and competency-based e-learning approaches for learning on demand (Schmidt & Kunzmann, 2007). Furthermore, the educational ontologies mainly concentrate on learning objectives, curriculum and learning contents, such as (Al-Yahya, et al., 2013), (British Broadcasting Corporation (BBC), 2013) and (Cobos, et al., 2013).

Taking account of the above discussions, some existing ontologies are reused (cf.Chapter 3.6.1) so that successful components can be extracted and used in the building of a new ontology model. It should be emphasized that none of the domain specific ontologies described in the literature (Chapter 2.4) are modeled on the WoC, which is shaped from the melting point of the WoW and the WoE to explore KSC demands and matched with KSC supplies to figure out the KSC balance, as stated in a form that the author described in this study.

In this way, the author's motivation to contribute to this research is perceived in three dimensions. First, developing ontology is one reasonable solution not only to represent knowledge of the field but also to support inferences and semantic reasoning (i.e. semantic matching of WoW and WoE and reasoning of WoC). Second, a well-defined ontology should be usable and interpretable for non-technical people, thus, developing the ontology confronts a great challenge with regard to social quality and maturity. Third, identifying the melting point of two interdisciplinary domains, WoW and WoE, lead to providing one picture of the WoC, matching space, and in the form of Job-Know Ontology considering the changes of supply-demand over time.

1.3 Research Objectives, Questions, Contributions, and Restrictions

The primary objective of the thesis is to provide an ontology entitled Job-Know Ontology to represent the WoW and WoE domains. Job-Know Ontology matches these two domains and

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[2] The domain specific ontologies are described and discussed by Chapter 2.4.

finally represents the WoC to reason whether the learning outcomes gained in the WoE are in balance with KSCs demanded a specific job. To fulfill this goal, three research objectives (O1-O3) have been set:

- O1. To semantically model the concepts and relations of the WoW and WoE (i.e. VET not HE) from the perspective of the melting point, which is model WoC.
- O2. To semantically match the WoW and WoE, towards inferring the states of supplied and demanded KSCs over time.
- O3. To propose a detailed methodology not only for developing the meta-model of the ontology (T-Box) but also for instantiating the ontology in a specific domain (A-Box).

With respect to the objectives of the research, four research questions (RQ) are defined. In the following, the RQs and the chapters, which discuss them are mentioned.

- RQ1. Is there any ontological model, which represents WoW, WoE and the semantic relation between them? ⇒ Chapter 2 provides the answer.
- RQ2. What are the concepts and relations defined to model WoW and WoE and ultimately infer WoC semantically? ⇒ Chapter 2 identifies the existing concepts and relations defined by the literature, while Chapter 4, 5 and 6 introduce the concepts and relations defined by the author.
- RQ3. What is the state of the supply-demand of a KSC? ⇒ Chapter 6 presents the model and elaborates on relations to infer the matching states of a KSC.
- RQ4. How can Job-Know Ontology be applied and employed in different domains? ⇒ Chapter 7 presents a use-case in the nursing domain to evaluate the Job-Know Ontology and also describes how the A-Box of the ontology should be instantiated.

By this thesis, the author has contributed to the research as described below:

- C1. Domain-independent semantic representation of the concepts and relations in the WoW and WoE.
- C2. Matching mechanisms to infer the states of learning outcomes supplied by WoE and KSCs demanded by WoW over time.
- C3. The novel mechanism to transit supply-demand of KSCs to balance state in the WoC.
- C4. Comprehensive methodology to develop T-Box and A-Box of the Job-Know Ontology.

Finally, the restrictions, which describe the limits of this work, are summarized below, and are to some extent connected to future research objectives (cf. Chapter 8.2).

- R1. This study focuses on the European perspective of WoW and WoE, particularly Germany. However, there is a demand to expand the work into the other national and international societies.
- R2. Although this work is evaluated in the nursing and partially production-logistics domains, there is a need to implement the work in other domains to to find out what is missing/lacking and to fill the gaps.
- R3. The knowledge acquisition from documents, in particular, ISCO[3] and ISCED[4] to assert the Job-Know Ontology is not (semi-)automatic (i.e. ontology learning methods). This provides an opportunity to consider automatic ontology learning approaches in the context of future work.

1.4 Thesis Structure

As shown in Figure 2, Chapter 2 consists of the literature review: first it discusses the theoretical background in relation to the WoW and WoE, and second, the technical background (i.e. the methodologies of ontology development and domain specific ontologies). Chapter 3 provides the details of motivating scenarios, competency questions, and the methodology to develop the Job-Know Ontology. Chapter 4 specifies, conceptualizes, and formalizes the WoW domain of the Job-Know Ontology. Similarly, Chapter 5 specifies, conceptualizes, and formalizes the WoE domain of the Job-Know Ontology. Chapter 6 states how the WoW and WoE are modeled within the supply and demand spaces and consequent matching space in WoC. Furthermore, this chapter presents how the supply-demand states are inferred through using the semantic relations defined in supply and demand spaces. Finally, this chapter discusses time factor, essential to be taken into account to respond in right time to the demands requiring action from WoW and/or WoE. Chapter 7 presents the instantiation of Job-Know Ontology as well as realization and implementation results of the Nursing Job-Know Ontology which is an integral part of the knowledge-bases of two multilingual nursing VET assistance systems: Professional Nursing Education and Training (Pro-Nursing) (Khobreh, et al., 2016) and Web-based e-learning system for nursing students and nurses (Wissenspflege) (Khobreh, et al., 2016). The former was funded by the European Commission in the context of Erasmus+

[3] International Standard Classification of Occupations

[4] International Standard Classification of Education

programme (2014-2016), and the latter was a student project in cooperation with regional nursing schools in Siegen, Germany (2013-2017). This chapter also discusses the domain-independency of the proposed model and extends the scope of instantiation to the production-logistics in the context of the regional industry partnership project entitled "Ontological Approach for Developing a Knowledge Base of the Production-Logistic" (OntoLog) (2015-2016). Chapter 8 concludes the thesis, discusses the key findings of the work, as yet unresolved issues, and offers suggestions for future works.

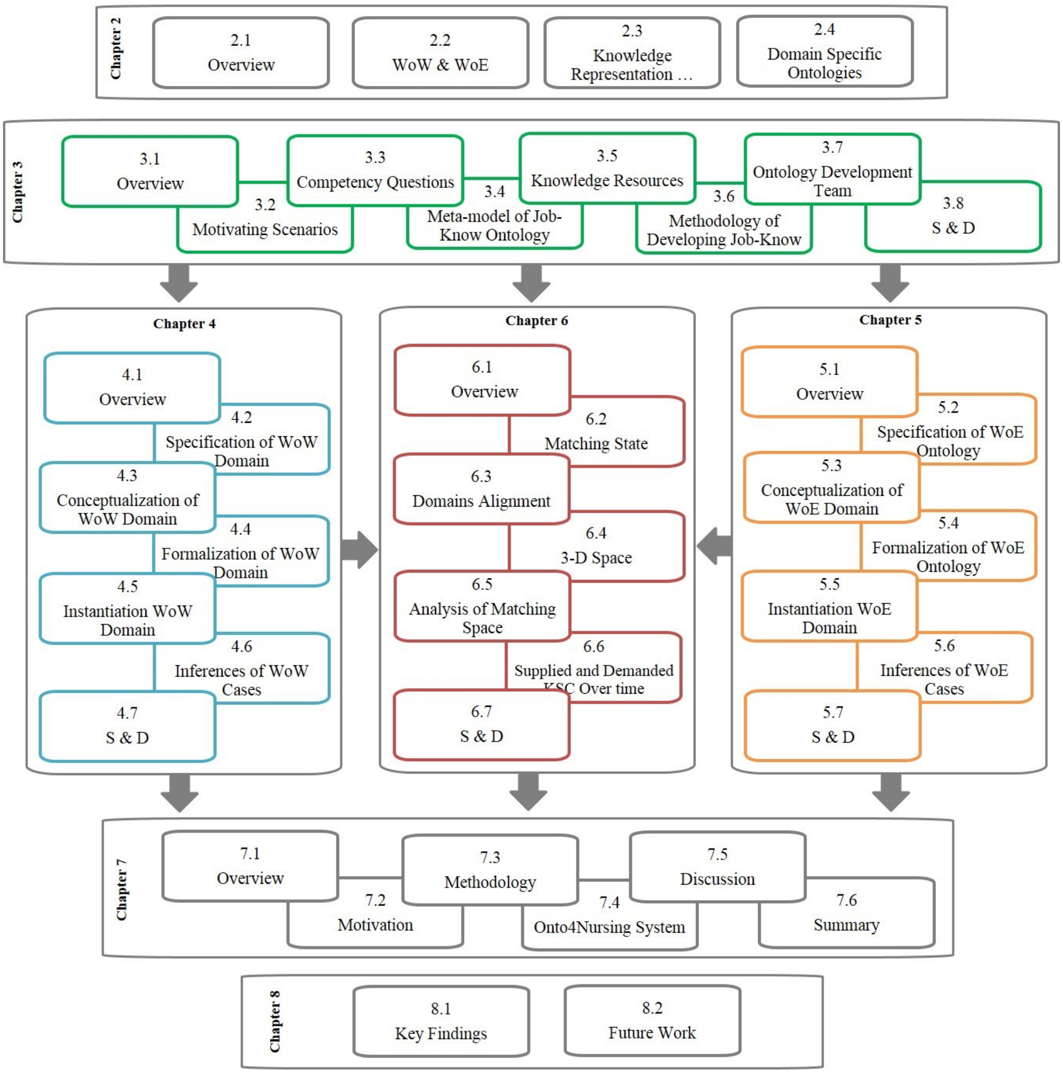

Figure 2 Structure of the dissertation and the relations between the Chapters

2 Literature Review

2.1 Overview

This chapter provides a state-of-the-art analysis for deepening insight into two fundamental parts of the present thesis, i.e. firstly job specified knowledge theories and models, and secondly ontology development. The chapter consists of three main sub-chapters as follows: i) the bodies of literature exploring the WoW and WoE, including related key-terms, definitions, and the challenges in establishing a communication channel between them - defined in this thesis as World of Competence (WoC) (cf. Chapter 2.2), ii) the bodies of literature which discuss the methodologies and frameworks for ontological knowledge representation towards providing knowledge-based solutions for WoC (cf. Chapter 2.3), and iii) the bodies of literature which examine domain specific ontologies, specifically competence and educational ontologies (cf. Chapter 2.4). This literature survey lays the ground work identifying the demand to provide a semantic solution for connecting the WoW and WoE via the WoC and specifies the requirements for developing a new knowledge-based solution known as Job-Know Ontology, beyond the state-of-the-art.

2.2 Worlds of Work and Education

2.2.1 World of Work

The WoW consists of occupations and jobs. International Labor Office (ILO) defines an occupation as "a set of jobs whose main tasks and duties are characterized by a high degree of similarity" and accordingly a job as "a set of tasks and duties performed, or meant to be performed, by one person including for an employer or in self-employment" (International Labour Office, 2012). The job consists of duties, which is a collection of tasks, a task is a collection of activities, and an activity is a collection of groups of elements. Finally, an element (e.g. recording the patient information in the nursing job) is the smallest unit of a job, which has a beginning, middle, and end (Brannick, et al., 2007). One should distinguish between the terms "job" and "role". "A role is the part play people in their work", which is about the people, while "jobs are about the tasks and duties" (Armstrong & Taylor, 2014). In the present thesis, the focus is on "job" and not on "role".

The tasks of a job, which should be performed by the jobholder(s), are described in a job description defined by an employer, and more specifically, the job designer. While the former describes the job based on the demand of his/her organization, the latter aims at standardizing the job independent of any organizational relation. A job description is about the tasks rather than outcomes of the tasks, and about the duties more than competences required to perform the duties (Armstrong & Taylor, 2014), (Breaugh, 2017). The job description mainly includes the list of the tasks, which descriptively identify what should be performed in the frame of the job. Job descriptions are provided in different detail levels, that reflect the percentage of time spent on each task, the frequency of performing the tasks, how the task is connected to the other job tasks and/or jobs of the organization (Grant, 1988). A job specification refers to the qualification and abilities required to enable the jobholder to perform the job satisfactorily, and therefore, it ideally includes education level, experience, specific competences and personal characteristics (Brannick, et al., 2007), (Breaugh, 2017).

The job description is used for different purposes which include 1) assisting the employer, who announces a job, and the job applicant to have a shared understanding of the job tasks (Cascio, 1998), (Brannick, et al., 2007), 2) job evaluation to determine the value of each job comprising the jobs of organization and finally to establish a payment structure (Hahn & Dipboye, 1988), and 3) evaluating the performance of the jobholder to determine whether or not the assigned tasks are being performed appropriately and that the job holder has the required KSCs to perform the job (Cascio, 1998).

In this thesis, to identify a job, related job descriptions and specifications are required for various stakeholders, employers, and job applicants (potential employees of future). By the first one, the employer makes the agreement with the employee about what should be performed in the frame of this job, and by the latter, the demanded KSCs, which enable employees to perform the described tasks, are determined by the employer (Khobreh, et al., 2016).

KSC is necessary for performing an activity, which is specifiable, definable, and measurable (Allen and Pilot 2001). Having KSC ensures possessing the necessary attributes to perform an activity competently (Burgoyne, 1988). Referring to the definition of the European Parliament, knowledge means “outcome of assimilation of information through learning knowledge is the body of facts, principles, theories, and practices related to a field of study or work”, and skill means the “ability to apply knowledge and use know-how to complete tasks and solve problems”. However, different definitions of the term “skill” exist in the literature. The Anglo-Saxon defines the vocational skill, which is associated with “the attribute or property of an individual”, “the performance of discrete tasks”, “physical or manual dexterity” and is not necessarily associated with “a particular knowledge base” and/or “to the possession of a qualification” (Clarke & Winch, 2006).

The focus of German vocational education[5] is placed on “the ability to apply theoretical knowledge in a practical context” (Clarke & Winch, 2006). Finally, competence means “ability to use knowledge, skills and personal, social, and/or methodological abilities, in work or study situations and in professional and personal development” (European Parliament, 2008).

As shown in Table 1, competence refers to both “professional” and “personal” competences and consequently, “professional competence” is subdivided in “knowledge” and “skill”, while “personal competence” is subdivided in “social competence” and “autonomy” (German Qualifications Framework Working Group, 2013).

Table 1 Knowledge, Skill, and Competence according to DQR Classification (German Qualifications Framework Working Group, 2013)

Professional competence		***Personal competence***	
Knowledge	***Skills***	***Social competence***	***Autonomy***
Depth (penetration of area) *Breadth (number of areas)*	*Instrumental* *Systemic* *Judgment*	*Team/ leadership skills,* *Involvement* *Communication*	*Autonomous responsi-bility/ responsibility Reflectiveness* *Learning competence*

Meta-competence concerns not only “how to apply skills and knowledge in various task situations”, but also “how to acquire missing competences” (German Council for Research, Technology and Innovation, 1998). At this stage, it is worthwhile to define the direct relation between the job tasks and KSC needed, and the link and interrelation of the elements of the KSC. While KSC enables individuals to perform the given tasks, meta-competence is essential to active monitoring, development, and improvement of knowledge and skills, which lead to having sufficient and relevant KSC (Winterton, et al., 2006). Acquiring meta-competence is resulted from continuance learning and is an enabler to possess KSC over time.

2.2.2 World of Education

Education is an everlasting and life-long process, which starts from training and learning, ends one cycle with assessment and receiving feedback on knowledge level, and continues in a spiral form to achieve and sustain improvement and relearning (Kolb & Kolb, 2005). There are two modes of learning: i) learning based on science and technical knowledge (to learn

[5] In German: Berufsbildung

know-what), and ii) learning based on doing, experiencing and interacting (to learn know-how) (Jensen, et al., 2007).

Learning environments are distinguished into four types: i) *learner-centered* concentrates on learners ("who" should learn), ii) *knowledge-centered* concentrates on knowledge, skills, and ability ("what" should be learned), iii) *assessment-centered* provides feedback on the knowledge level for learners and education process for educational institutions ("how much" and "to what extent" is learned) and iv) *community-centered* focuses on the place, e.g. class-room, virtual forums, communities of practice, or home, depending on formal, semi-formal, non-formal and informal learning ("where" learning process is implemented) (Bransford, et al., 2000), (Edgar, 2012).

Vocational education and training (VET) aims at combining "know-what" and "know-how", and providing specific lessons for those wanting to learn wants to learn a specific job at the end of the learning process. These lessons might be taught in school and/or work to obtain KSCs demanded by the WoW (Cedefop, 2014) .The European Centre for the Development of Vocational Training (CEDEFOP) stated that VET "aims to equip people with knowledge, know-how, skills and/or competences required in particular occupations or more broadly on the labor market" (Cedefop, 2014). European cooperation in education and training (ET 2020) and the Bruges communiqué on enhanced European Cooperation in VET for the period 2011-2020 emphasize modernizing VET, making VET more learner employment responsive (European Union, 2009), (European Union, 2011). This literally means that the learners should possess various set of KSC, which are required either for a specific job or more broadly for (the target) labor market. The latter enables the learners to switch from one job to another more easily, while they perform assigned tasks competently. In this way, the European Council, ILO, and CEDEFOP agreed to enhance the employability, productivity, and income-earning capac-ity of the learners while focusing on supplying the demands of a knowledge-based society (Granados, 2012).

VET combines theoretical and practical learning to train the learners who, in an ideal case, are ready at the end of the learning process to join the WoW (Chatzichristou, et al., 2014). The learning places of VET, where the learning units are implemented, are distinguished into three groups: i) *school-based VET* where both theoretical and practical training takes place in schools, ii) *mixed VET* where training is mostly school-based but there are some work-based elements, and iii) *work-based VET* where the major part of the learning takes place in the actual or simulated workplace (Chatzichristou, et al., 2014). Notably, "dual education" and "alter-nance training" are categorized as VET. The former refers to apprenticeship-based programmes where there is contractual relation between learners and employers, while the latter does not necessarily consider that learners should be paid by employers (Chatzichristou, et al., 2014).

In this context, Pilz defined "6 P strategy for VET" as i) Priorities: to identify training needs from training policy perspective, and in particular, learners, trainers, and employers, ii) Power: to identify the resources such as equipped teaching and training rooms and modern, target group-specific curricula, teaching and learning materials, iii) People: training staff able to manage meaningful learning process, iv) Poaching-avoidance: firstly to involve the employees in the training process, secondly to identify clear advantage for the company initiating the in-company training and skill development, v) Progression: to measure and certify the learners, and vi) Privileges: to ensure "adequate working conditions and pay for trained staff" (Pilz, 2016).

In recent years, major European countries redesigned their VET curricula and placed the focus on learning outcomes oriented approaches. The outcomes-oriented VET curricula equip the individuals with specific KSCs, which they (may) need in the WoW (Cedefop, 2012). However, countries such as Germany, France, the Netherlands, and the UK had recognized the curriculum reformation needs as early as the 1980s, which led to the outcomes-oriented curricula of today (Cedefop, 2010).

Curriculum, as generally defined, is the "description of a body of knowledge or of a set of skills; a plan of teaching and learning; an agreed standard or contract; the experience of learners over time" (Cedefop, 2010). Moreover, the learning outcome of a VET curriculum is defined as "a normative document (or a collection of documents) setting the framework for planning learning experiences" (Cedefop, 2010).

The European countries (re)designed their own National Qualification Framework (NQF) based on the European Qualification Framework (EQF) (Cedefop, 2015). EQF defines what learners should acquire at the end of a learning process, defined as learning outcomes (European Parliament, Council of the European Union, 2008), and establishes the framework on this basis. The learning outcome is considered as an umbrella term overarching KSC obtained through learning a specific field (European Commission , 2010). Learning outcome as the result of outcome-oriented VET connects the WoW and WoE and is thus is credited (Cedefop, 2012). In the context of EQF, knowledge is described as theoretical and/or factual, while skills are described as the use of logical, intuitive and creative thinking (cognitive), and also the use of methods, materials, tools, and instruments (practical) (European Parliament, 2008). In this context, competence is described as the ability to use knowledge and skills categorized as professional competences and responsibility, and autonomy is categorized as personal competence (German Qualifications Framework (DQR), 2011), (European Commission , 2010). KSC is, therefore, defined domain-independent.

Considering the aforementioned discussion on WoW and WoE, one may investigate how to connect (to establish a communication channel between) these two worlds? Section 2.2.3 elaborates on this issue.

2.2.3 Connecting WoW and WoE

Education, and consequently its learning outcome, is highly relevant to the WoW (European Commission, 2014). The European company survey (ECS) in spring 2013 found that 39% EU-companies had difficulties hiring employees with the right skills (Eurofound, 2013). "One in three European employees is considered to be either overqualified or under-qualified for the jobs that they do" (European Commission, 2014). Countries with the high rates of over-qualification (such as Greece) do not have a clear plan of investment in the status of public education and training and the programmes of the labor market, in addition to having an inflexible labor market (European Commission, 2014). Likewise, the pace of changes in WoW and WoE is not the same in the countries confronted with under-qualification job applicants (i.e. qualitative skill shortage) (European Commission, 2014).

Moreover, demographic aging, particularly in the north European countries (e.g. Germany), turns the employment growth negative; therefore, the source of economic growth is dramatically decreasing, while the demand for skill-workers is increasing (European Commission, 2014). The WoW also exposes the technological changes (e.g. due to digital transformation and automation) and mobility of skill workers, which may lead to skill imbalance problems. In fact, to reduce inefficiencies, exploit innovation potentials, and come to stronger productivity gains, there is an obvious need to invest in forming, maintaining, and using human capital to secure sustainable levels of employment (European Commission, 2014). The risk of skill imbalance increases in knowledge-intensive economies since new jobs require new/emerging KSCs over time (European Commission, 2014). To tackle skill imbalance problems, action on both sides of supply and demand is needed. With respect to this, not only the WoE needs to increase the flexibility and responsiveness to the demands of the WoW, but also the WoW needs to create innovative and high-skilled jobs (European Commission, 2014).

In this era, a common global concern of WoE, in particular VET, and WoW can be described in two conditional phrases, respectively:

- whether the learning outcomes, which the individuals as learners obtain in VET, can meaningfully meet KSCs required in practice, and
- whether the individuals as employees are able to perform the job tasks, based on the learned KSCs.

If not, the individuals, who have been/are trained in VET, do not possess sufficient and/or relevant KSCs to perform the assigned job tasks competently. The challenge of the WoE, particularly VET, is to supply the demands of the WoW in the right time. Otherwise, the WoW will face KSC imbalance problems. An employee, in general, is either a newcomer (e.g. young graduated individual), or, an existing employee who may be experienced and should be promoted. Both types of employee may face an imbalance between KSCs possessed and KSCs required. The newcomer may suffer KSC imbalance due to the weakness of the education system in which he/she studied, and the latter due to the inappropriate response to changes occurring in the technology and/or service, as well as inappropriate on-the-job training. As a consequence, both cases reduce productivity (European Commission, 2014). Further, the WoW requires that the WoE ensures the availability of skilled employees. The WoE, particularly VET, should know what needs to be taught to learners, who are potential future employees. Individuals as (current and/or future) employees need to know what KSCs should be possessed to perform the job competently, and learners need to know what KSCs are obtained by finishing the learning process (i.e. learning unit or learning field).

Dealing with the challenges of WoW and WoE towards overcoming imbalance problems, a communication channel, or mediator is required, which connects the WoW and WoE. In this thesis, WoC connects the WoW and WoE (cf. Figure 3) and facilitates the process of analyzing whether or not supplied KSCs and demand KSCs are in balance.

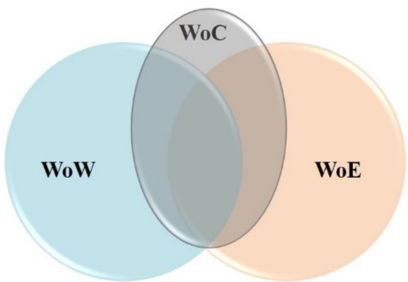

Figure 3 The melting point of WoW and WoE, which is WoC

On the one hand, the WoW benefits the WoC to hire employees, particularly those who recently graduated and possess right KSCs (including new/emerging KSCs) to perform certain jobs. Thus, the WoW does not need to spend resources to (re)train the newcomers. On the other hand, the WoE is of benefit to the WoC to ensure what should be supplied as learning outcomes is in balance with the demands of the WoW (i.e. the learning outcomes which should be possessed at the end of the learning process are sufficient and up-to-date to perform certain jobs).

Furthermore, we go beyond the constitution of WoC at the conceptual level and aim to propose a framework and knowledge-based ICT[6] tool to connect WoW and WoE and to provide assistance on the exchange of information between them via WoC. To achieve these goals, such a tool consists of modules and associated functions, which support identifying the new/emerging KSCs as well as gap, shortage, surplus and obsolete KSCs supplied by WoE and demanded by WoW. Table 2 discusses the main benefits of WoC in association with its stakeholders.

Table 2 Who benefits from WoC adopted from (Lassnigg, 2012)

Who benefits (Stakeholders)	***How benefits***
Policy-makers	*To monitor changes, provide respected requirements, and set the strategies.*
Employment service providers	*To acquire information for their activities such as career guidance and provide information to employers about skills availability.*
Training providers	*To acquire information about emerging or expected skill needs in companies as well as public sector workplaces, which ensures that course content is in line with future demand.*
Individuals	*To look for study alternatives, opportunities for future employment, and career advancement or change.*

2.3 Knowledge Representation to provide Semantic Solution

One of the main concerns of computer science is processing of data. Around 50 years ago, due to a need to manage simple and complex datatypes, data was separated from the application and databases were defined. However, as information retrieval (Manning, et al., 2008), information extraction (Moens, 2006) and natural language processing (Jurafsky & Martin, 2014) were evolved to cope with digital natural language documents and human knowledge, the simple databases could not respond to the needs of the evolving environment in the complex cases. Consequently, knowledge representation (Sowa, 2014) and knowledge engineering were established to provide methods and techniques to represent implicit and explicit knowledge in machine-readable format (Schreiber, et al., 2000).

[6] Information Communication Technology

The main task of knowledge representation is semantic modeling of knowledge-bases, which "is a technology used to store complex structured and unstructured information used by a computer system" (Marakas, 2016). As the need for knowledge-based systems and subsequent knowledge-bases rose, the focus on specific type of knowledge representation known such as the ontology development (engineering) was scaled up. Ontology, in a nutshell, is a specification of a shared conceptualization (Guarino, et al., 2009) in machine readable format (Guarino & Giaretta, 1995). To formalize ontology, the languages of the logic, such as first-order logic (McCarthy, 1960), propositional logic (Post, 1921), and description logic (Baader & Nutt, 2007) are used (Lifschitz, et al., 2008).

Recent studies in different fields indicate that ontologies are widely considered to be an appropriate knowledge representation technology (Niknam & Karshenas, 2017), (Tarus, et al., 2017), (Cai, et al., 2011), (Gaeta, et al., 2011), (Cai, et al., 2011), (Gaeta, et al., 2011), (Razmerita, 2011), (Shah & Musen, 2009), (Zhao, et al., 2009) (Bittencourt, et al., 2009). Notably, developing the ontologies has grown drastically after standardization of the Web Ontology Languages (OWL) (Matentzoglu, 2016).

The benefits to use and/or build up an ontological knowledge-base are as follows (Biesalski & Abecker, 2005):

i. Conceptualizing and structuring the domain of the interest from an abstract to a detail level in a taxonomy form.

ii. Reengineering the existing ontological and/or non-ontological resources to create the best-fit ontology solution.

iii. Discarding, adding, and editing the ontology nodes to keep the ontology updated.

iv. Measuring similarities of the nodes of two (or even more) ontologies to support matching process.

Besides the advantages of developing ontology as a knowledge base, there are some technical challenges within the process of developing the ontology, which should be taken into account and are described in the following:

- Building up the development team consists of ontology engineer(s), knowledge engineer(s), end-user(s), and domain expert.
- Managing time from creating the first version to providing the final version. Since the development team should be involved in the ontology development process and they are from different disciplines, assigning the tasks of each discipline at the right time is essential.

- Providing a best-fit version, which depends not only on time and budget but also on the competences of the development team (Biesalski & Abecker, 2005). Notably, enrichment and improvement of an ontology will be everlasting in an evolutionary environment.

2.3.1 Conceptual Modeling with Ontology

Ontology is developed based on the description logics (DL) mostly fragmented from first-order logic (Baader & Nutt, 2007). The ontology mainly describes a domain by using concepts (unary predicates), roles/relations (binary predicates) and individuals (constants) (Baader & Nutt, 2007). The ontological knowledge-base consists of T-Box and A-Box, where T-Box includes the terminologies, composed of concepts and roles, and A-Box includes the named individuals, that belong to the concepts and are related via roles to the other individuals (Baader & Nutt, 2007). The concepts and roles, which are the core parts to define the other concepts, are called atomic. The atomic concepts and atomic roles are used to build up the complex descriptions (Baader & Nutt, 2007). Furthermore, the A-Box introduces the individuals i.e. by giving them a name. An individual can be introduced in two kinds; concept assertion and role assertion (Baader & Nutt, 2007). The first kind is an instance, which belongs to a concept(s) (1), and the latter is an instance related to another instance (2). Using concept C, role R and individual a, b to show two aforementioned kinds in an A-Box:

$$C(a) \tag{1}$$

$$R\ (a, b) \tag{2}$$

In general, the schema of a relational database can be mapped to the T-Box of the knowledge-base, and the database instances to A-Box. However, the semantics of classical database is “closed-world”, while A-Box semantics is “open-world”. In other words, knowledge defined in a database is complete, which is not the case in an A-Box. Furthermore, T-Box of the knowledge-base defines the semantic relationships between the concepts and roles, which should be followed in the A-Box. This process does not occur in database semantics (Baader & Nutt, 2007).

2.3.2 Ontology Development Methodologies: An Overview and Discussion

To develop ontology systematically, the different methodologies are established. The abstracts of the methodologies are summarized by the author and provided in the Appendix 1-Table 22. Providing a summary of these methodologies, the creation of WoC specific ontology development methodologies is discussed in this section.

UPON-Lite focuses on how non-ontology engineers (i.e. end user and domain expert) can develop an ontology (De Nicola & Missikoff, 2016). It includes the six steps of ontology engineering, namely, 1) domain terminology 2) domain glossary 3) taxonomy 4) prediction 5) parthood, and 6) coding ontology formally.

The **NeOn** methodology includes a glossary (i.e. 59 processes and activities) (Sua´rez-Figueroa, 2010), a set of nine scenarios, two ontology network life cycle models, and a set of guidelines (Suárez-Figueroa, et al., 2011). The nine-NeOn scenarios include Scenario 1: From specification to implementation, Scenario 2: Reusing and re-engineering non-ontological resources, Scenario 3: Reusing ontological resources, Scenario 4: Reusing and re-engineering ontological resources, Scenario 5: Reusing and merging ontological resources, Scenario 6: Reusing, merging, and re-engineering ontological resources, Scenario 7: Reusing ontology design patterns (ODPs), Scenario 8: Restructuring ontological resources, and Scenario 9: Localizing ontological resources. All the scenarios include processes (so-called support activities): knowledge acquisition, documentation, configuration management, evaluation, and assessment. NeOn scenarios can follow two life cycle models, either a waterfall model or iterative-incremental model.

Distributed Engineering of Ontologies (DILIGENT) Methodology (Pinto, et al., 2009) focuses on decentralization, partial autonomy, iteration, and non-expert builders. Ontology engineer(s), knowledge engineer(s), domain expert, and ontology user(s) are directly involved in the DILIGENT process to build the ontology regardless of their location. DILIGENT introduced two kinds of ontologies. One is the shared ontology, which is available to all users but evolved just by the board. The board created the shared ontology and is responsible for the evolving process. The other is a local ontology, which is a copy of the shared ontology; however, the user can freely change this version as needed.

The **Unified Process for ONtology (UPON)** is a use-case driven methodology (Antonio, et al., 2009) which consists of four phases: (1) inception to capture requirements, (2) elaboration to identify the fundamental concepts, (3) construction to design and implementation of the ontology, and (4) transition to testing the ontology. Each phase can have an iterative workflow including requirements analysis, design, implementation and test, but the focus on each workflow depends on the respective phase. The four phases make a cycle and, when completed, a new version of the ontology which is more appropriate than the previous version is provided (Antonio, et al., 2009).

The **On-To-Knowledge** is a generic ontology engineering methodology which includes five main phases: i) feasibility study phase to identify the problem and potential solutions, ii) kick-off phase to clarify what this ontology should support and sketch the planned area of the ontology, iii) refinement phase to formalize a refined semi-ontology into the target ontology, iv) evaluation phase to evaluate the ontology from the perspective of technology, users, and end-product, and v) evolution phase to apply changes and to switch-over to a new version of the ontology (Sure, et al., 2009).

Human-Centered Ontology Engineering Methodology (HCOME) discussed the importance of involvement of knowledge workers including knowledge engineers to develop and evolve the resultant ontology (Kotis & Vouros, 2006). HCOME encompasses three phases: i) specification to define aim, scope, requirement, and team, ii) conceptualization to acquire knowledge, develop and maintain ontology and finally iii) exploitation and verification to use and evaluate ontology (Kotis & Vouros, 2006).

METHONTOLOGY incorporates a methodology which was developed through management (i.e. planning, control and quality assurance activities), development (i.e. specification, conceptualization, formalization activities), and support (i.e. acquisition, integration, evaluation, documentation and configuration activities) (Fernández-López, et al., 1997).

TOronto Virtual Enterprise (TOVE) methodology defines four steps to develop the ontology: i) providing a motivating scenario in the form of the story problems, ii) defining the informal competence questions, iii) defining the terminology, iv) defining the formal competency questions, v) evaluating the proposed ontology (Grüninger & Fox, 1995).

Uschold and King developed a methodology to: i) identify the purpose and the scope, ii) build the ontology (i.e. capture the concepts and relationships, coding, integrating existing ontologies), iii) evaluate the implemented ontology, iv) document formal and informal discussions (Uschold & King, 1995).

As a result, there are clear similarities between the aforementioned methodologies as follows:

- Each methodology stresses the start point and recommends a thorough feasibility study, kick-off, identification of the purpose, specification, and well-defined competency questions.
- Rather than starting from scratch, each methodology recommends redesigning, reusing, and re-engineering existing ontologies.

- The methodologies mainly define separate stages to produce informal and formal ontologies, respectively, to bridge the gap between the real world and the executable system.
- Most of the methodologies present maintenance and evolution of the ontology as the final phase, which encompasses an iterative process.

Some of the methodologies (such as METHONTOLOGY, NeOn) classified knowledge acquisition, documentation, configuration management, evaluation, and assessment as support activities, although they are named as the main body of the methodology defined by Uschold and King. There is a similarity between the development activities described in METHONTOLOGY and the first scenario of NeOn, both start with the specification, go ahead with conceptualization and formalization, and end by implementation. However, the steps/phases discussed by the other methodologies are not far from these four methodologies. DILIGENT and HCOME focus on the team who develop the ontology and how they should develop the ontology collaboratively. Both point out the importance of the role of knowledge workers and domain experts and discuss the resultant ontology which cannot be completed, except by involving the end-users, domain expert and knowledge workers in the phases of developing the ontology. UPON-Lite stresses identifying the terms (i.e. concepts, relation, and individuals) by the end-users and/or domain experts. These steps can be considered as specification and conceptualization phases as defined by the other methodologies, however, to formalize and codify the conceptual ontology, ontology engineers should be involved.

The **Job-Know Ontology** is a domain-independent ontology, therefore, our approach was first to develop the T-Box of the ontology and then instantiate it based on the individuals of the selected job and education domains to create the A-Box. Since none of the methodologies could fully fit with our need (i.e. developing T-Box and A-Box separately), we established our own methodology (cf. Chapter 3.6). To develop the T-Box, define the concepts and roles as meta-model and then conceptualize them in detail level, the developing plan-1 is defined (cf. Chapter 3.6.1). **The four phases (i.e. specification, conceptualization, formalization, and implementation)** of this plan is based on the activities specified by **NeOn-Scenario1** and **METHONTOLOGY-Technical actives**. The activities of the specification phase which are describing the **motivation scenario(s)** and the defining of the **competency questions** are organized based on the two first steps of **TOVE** and on the **identification of scope and purpose** from methodology developed by **Uschold and King**. This is also stressed by **UPON's first workflow**. The **conceptualization phase** in our methodology focuses on defining the concepts and roles of the domain, which includes the first fourth steps of **UPON-Lite**. The conceptualization phase is closer to the **elaboration phase of UPON**. The **formalization phase** of our methodology is like **the third step of TOVE**, which defined the informal ontology by using first-order-logic. Finally, the **implementation activities** of our methodology are close to the activities defined by t**he fourth workflow of UPON and NeOn**. In addition to developing T-Box, we will develop the A-Box of the domain of the interest. To do so, we defined a phase called ***Instantiation***, which is not noted by any methodologies studied here, at this level of specification.

To conclude the discussion on the methodologies, our methodology is a **hybrid-methodology** inspired by the aforementioned methodologies studied in this work (cf. Appendix 1) and includes the new Instantiation phase.

2.4 Domain Specific Ontologies

Considering the scope of the present thesis, it is essential to study the existing ontologies provided to represent labor market, education, and competence development. The aim is to figure out what is available as a resource (i.e. conceptualized ontology, formalized ontology and/or codified ontology) and can be used in the context of the present work. In the following, the existing ontologies of WoW and WoE are classified generally into two groups of competence development ontologies and educational ontologies. It is worthwhile to highlight that ontologies are grouped based on their main characteristics, objectives, and elements. In other words, there are some ontologies, particularly in the competence development group, which may have some overlaps with elements of educational ontologies, yet they are belonging to competence ontology group due to their main objectives.

2.4.1 Ontologies for Representation of Competence Development

There are a number of ontologies conceptualized and/or formalized for representing the relation between job, employee, and competence in the context of competence development (CD) - sorted below by publishing time order starting from the recent ones.

CD-Ontology 1: an ontology model is developed for managing competence in the context of SIRET project (Miranda, et al., 2017). The goal of SIRET project is “recruiting and training integrated system” (Miranda, et al., 2014). The developed ontology is divided into static and dynamic parts. The former part includes professional profile, competence, context and it is person-independent. The latter part is person-dependent and represents the competence acquired by a specific individual.

CD-Ontology 2: **LO-MATCH** is a platform created within the frame of informal and non-formal competences matching device for migrants' employability and active citizenship

(MATCH project)[7] to compare resume, job offers and qualification, which uses an ontology to represent knowledge, skill, and competence. Referring to EQF definition, LO-MATCH represents knowledge as a set of Knowledge Objects (KO), a skill as a KO put into action verb (AV), and finally a competence as the ability to put into action a KO in a specific context (CX). So, a triple KO–AV–CX is determined LO-MATCH: A Semantic Platform for Matching Migrants' Competences with Labor Market's Need (Gatteschi, et al., 2012).

CD-Ontology 3: Fazel-Zarandi and Fox defined a **Skill Ontology** according to activity assignment and human resource recruitment. This ontology consists of three main concepts: i) Skill, ii) Knowledge Field, and iii) Activity (Fazel-Zarandi & Fox, 2012). The "in-field" relation is defined to connect Skill to Knowledge Field belonging to relation called "*enables()"* and connecting Skill to Activity and Proficiency Level to the ranking of the ability to perform the activity enabled by specific skill (Fazel-Zarandi & Fox, 2012). The relation of "*requires-value()*" connects Skill to Measured Attribute and Proficiency Level to determine the level of proficiency. The Measured Attribute has a unique specification set and a unit of measurement.

CD-Ontology 4: Single European Employment Market Place (SEEMP) project defined a **Reference Ontology**, which is built upon thirteen modular ontologies, namely: Competence, Compensation, Driving License, Economic Activity, Education, Geography, Job Offer, Job Seeker, Labor Regulatory, Language, Occupation, Skill, and Time. To develop the Reference Ontology, the HR standards such as NACE (Statistical Classification of Economic Activities in the European Community), ISCO-88 (International Standard Classification of Occupations, for European Union purposes) are used. The Reference Ontology acts as a common language in the form of a set of controlled vocabularies to describe the details of a job posting and the Curriculum Vitae(CV) of a job seeker" (Gómez-Pérez, et al., 2007).

CD-Ontology 5: The **HR-ontology** introduced by (Dorn, et al., 2007) is divided into three main sub-ontologies: competencies, occupations, and learning objects. The competences are defined as hard and soft competences, respectively, functional and behavioral. To measure the competences, they defined four main relations: i) *knowledge_value()* to aggregate the knowledge grade of a competency, ii) *experience_value()* to aggregate the experience grade of a competency, iii) *knowledge_level()* to describe the knowledge level, and iv) *experience_level()* to describe the experience level.

[7] Official project homepage: (accessed on 07.07.2017)

CD-Ontology 6: A **professional learning ontology** developed in (Schmidt & Kunzmann, 2007) represents a common understanding of competence management from the resource-oriented perspective and competency-based e-learning approaches for learning on demand. The top-level of the professional learning ontology consists of three super-concepts: *Learning Opportunity*: individual learning processes, *Organizational Entities*: tasks, processes, departments, and roles of the organization, and *Competency Evidence*: the evidence that shows the level of competence such as observation, training evidence, and self-assessment (Schmidt & Kunzmann, 2007). Moreover, the professional learning ontology provides three services for i) competence gap analysis, ii) selecting relevant learning opportunity, and iii) learning program compilation via defining the relation of *needs-competency* and *is-relevant-for*, respectively (Schmidt & Kunzmann, 2007).

CD-Ontology 7: In (Bizer, et al., 2005), the authors focused on developing an ontology towards decreasing transaction costs of employers for publishing job postings thereby increasing transparency in the labor market for job seekers, and ultimately improving person-job-fit. In general, this **HR-Ontology** is developed **to support recruitment processes** (Bizer, et al., 2005). The HR-ontology is divided into seven sub-ontologies, namely: skills, person, organization, industry, job posting, job application, and education. The HR-ontology has been derived from KOWIEN. It was created based on the HR-XML standard. Competencies were represented in the skills sub-ontology (Bizer, et al., 2005). These competencies provided the basis for the job-requirement and the employee skills descriptions. Also, the levels of particular competencies were handled within this sub-ontology. Person and organization sub-ontologies describe the relevant information about employees and the recruiting organizations. A matching algorithm was used to sample similarities between applicants' profiles and job requirements and to provide a ranking of the suitable candidates for a particular job (Bizer, et al., 2005).

CD-Ontology 8: providing a **skill-based HR-Ontology.** For this purpose, they have classified the human resource management (HRM) areas into two main categories: 1) change aspects: personnel recruitment, personnel placement, personnel development and dismissals, and 2) planning aspects: personnel planning, personnel controlling and personnel administration. According to the recommendations of (Scholz & Djarrazadeh, 1995), they went beyond HRM and concentrated on strategic HRM, so-called SHRM. With the SHRM points of view, actual and future human resources in companies should be taken into account, an adequate number of employees with the right skills in the right time and at the right place should be foreseen, and the strategic and HRM goals of the company should meet each other (Biesalski

& Abecker, 2005). SHRM has a strong interconnection with personnel development and consequently organized learning process to fill the gap between the actual and the future skill requirements (Biesalski & Abecker, 2005). In general, holistic competence management approaches try to fit competence-offers and competence-demands (Biesalski & Abecker, 2005).

Biesalski and Abecker defined the catalogs of Employee Competence Profile, Various Reference Profiles, Succession Planning, Training Offers, and Employee Training History to represent competence management. The catalogs are modeled by utilizing the ontology management tool KAON for DaimlerChrysler AG, Wörth Plant. Furthermore, the core process of the personnel development is planning for training. They discussed the appropriate way to justify how a piece of knowledge imparts competence with a specific weight through the process of training (Biesalski & Abecker, 2005). The skill ontology discussion mainly defines the relations between the employee, skill instance, position, and position skill requirement (Biesalski & Abecker, 2005). In this ontology, "position skill requirement" connects position to skill instance.

CD-Ontology 9: The KOWIEN project (Cooperative knowledge management in engineering networks) focused on developing an **ontology-based competency profile** (Dittmann & Zelewski, 2004). A central component of KOWIEN ontology and underlying concepts is to describe competence (Alan, 2003). The sub-classes of the concept of competence are divided into four groups: 1) "Facts competences" match the solid knowledge of the actor to the activity, 2) "Methodological skills" match the instrumental use to the actor for doing an activity, 3) "Social skills" correspond to communicative, cooperative and competitive personality traits of an actor, and 4) "Personal skills" match the reflexive personality traits of actor, which he/she can use to activity purposes. These include self-confidence, and self-esteem (Alan, 2003).

Notably, in practice, there are also significant works which aim to match the WoW and WoE; however, they do not necessarily hold an ontological approach for providing semantic solutions. Due to the importance of these **non-ontological approaches** and the possibility to use them as **non-ontological resources** in the context of Job-Know Ontology Framework (cf. Chapter 3.6), a brief overview is provided in the following.

The **dictionary of skills and competences (DISCO)**, which is a multilingual thesaurus of skills and competences subdividing skills and competencies into domain specific and non-domain specific (Markowitsch & Plaimauer, 2009).

Taxonomy-DB created by Swedish National Labor Market Board (AMS) consists of a repository of taxonomies for matching occupations based on ISCO to the needed skills based on ISCED (Markowitsch & Plaimauer, 2009).

Occupational Information Network (O*NET) is a database consisting of the six categories of: worker characteristics, worker requirements, experience requirements, occupational requirements, workforce characteristics and occupation-specific information (Peterson, et al., 2001).

European Commission published **European Skills, Competences, Qualifications, and Occupations (ESCO)** portal based on three pillars of occupations, competencies/skills and qualifications (European Commission, 2013). ESCO is a multilingual searchable database. ESCO occupations, competences/skills, and qualification pillars are structured, respectively, based on ISCO, considering transversal, cross-sector, sector-specific, and occupation-specific skills and competences (European Union, 2013).

In this way, Chala, Ansari and Fathi (2016) studied the aforementioned non-ontological occupational systems based on certain criteria which showed their diversity and accordingly proposed a **bi-directional matching approach** for identifying the degree of similarities of the job descriptions prepared by the job designers and job vacancies posted by employers (Chala, et al., 2016).

2.4.2 Ontologies for Representation of Education

Learning, like other fields, benefits from the digital era to establish learning management systems (LMS) which conduct learning via electronic, mobile, and web-based media (e-learning). One of the main components of LMS is the knowledge-base, which should be modeled, evaluated, implemented, and maintained. There are numerous ontologies, presented in the literature of education technology and technology-enhanced learning, which discuss employing an ontological knowledge-base in response to rapid changes, and to provide demands in right time. Furthermore, it is indispensable to point out the standards developed in the context of education and learning. In this section, firstly the educational ontologies, and secondly, the standards are studied are described.

Educational Ontology 1: The main goal of an ontological model for curriculum representation (CURONTO) ontology is to manage curriculum. CURONTO consists of eight concepts, such as *course*, *learning outcome (CLO)*, *student outcome (SO*), and *program educational objectives (PEO)*. *CLO* is mapped to *SO* and *SO* is mapped to *PEO*. Moreover, there is a direct relation between the course concept and all other concepts, except *SO* and *PEO*, which is related to the course indirectly (Al-Yahya, et al., 2013).

Educational Ontology 2: The British Broadcasting Corporation (BBC) has modeled curriculum ontology for describing the national curricula within the UK, organizing learning resources, and supporting users to find content via the national curricula. The **BBC curriculum ontology** provides a 3-D space, namely, the field of study, level, and topic with the sole focuses on education (British Broadcasting Corporation (BBC), 2013).

Educational Ontology 3: Pedagogical Patterns ontology (OntoPP) represents "the pedagogical patterns and their interaction with the fundamental concepts of the educational process" (Cobos, et al., 2013). **OntoPP** has been implemented using the ontology editing environment, Protégé[8], through rules and consisting of classes, namely, *Work-environment* which is divided to several sub-classes, such as *Knowledge-Area*, *Learning-Process-Objectives*, *Subject*, *Context*, *Learning-Style* (Cobos, et al., 2013).

Educational Ontology 4: **Concrete and Helpful Ontology-aware Collaborative Learning Authoring Tool (CHOCOLATO)** enables the users (i.e. novice and expert teachers) to select different learning theories and understand more about these theories (Isotani, et al., 2013). In addition, CHOCOLATO recommends the users utilize "theories, strategies, roles and group activities that can be performed by learners in order to achieve desired learning goals" (Isotani, et al., 2013). CHOCOLATO was built upon collaborative learning (CL) ontology (Isotani , et al., 2010). The CL ontology consists of CL scenario composed of two sub-concepts; *CL process* (i.e. how learners should interact to achieve their goals) and *learning strategies* (i.e. it represents the relation between two or more learners) (Isotani , et al., 2010).

Educational Ontology 5: **Student model ontology** consists of four classes: i) *Student* to represent any student, ii) *Student Course Information* to represent the student's performance, iii) *Student Current Activity* to capture any detail in terms of student's activity, which is divided into *Current Course Module* (i.e. the courses chosen currently), *Previous Experience* (i.e. the experience has previously been gained), and *Session Goals* (i.e. student's goals on a specific course) iv) *Student Personal Information* to represent student information including student preferences with the e-learning system (Panagiotopoulos, et al., 2012).

Educational Ontology 6: The structure of the **Learning Outcome ontology** is based on ABCD model (Mager, 1984). In this way, it consists of four classes: Audience, Behavior, Condition, and Degree. Moreover, learning outcomes are related to one or more learning objective represented by the class of *Learning Objective*. There is also an ontology developed

[8] http://protege.stanford.edu/ (accessed on 07.07.2017)

based on the revised Bloom Taxonomy (Anderson , et al., 2001). Finally, the Learning Outcome ontology and Bloom Taxonomy are combined to "assign learning outcomes to the various knowledge domains and levels of the Bloom Taxonomy" (Kalou, et al., 2012)

Educational Ontology 7: The **Ontology eLEarning (OeLE)** platform consists of ontology models to assess student exam results and to provide the numerical mark obtained by the students for each question and consequently for the entire exam (Castellanos-Nieves, et al., 2011).

Notably, the **education and learning standards** that provide metadata in form of vocabulary, taxonomy or ontology include Learning Resource Metadata Initiative (LRMI), Standard for Learning Object Meta data (LOM), Dublin Core, and Sharable Content Object Reference Model (SCORM). These standards are described in the following:

- ***LOM*** supports learners and teachers to "find educational materials through major search engines and specialized resource discovery services" (Barker & Campbell, 2014). LOM is an open and international standard developed by Institute of Electrical and Electronics Engineers Standards Association (IEEE) for the description of "learning objects" and specified by the IMS Global Learning Consortium (Barker, 2005). LOM is designed to create "well-structured descriptions of learning resources", where descriptions are used for "discovery, location, evaluation, and acquisition of learning resources by students, teachers or automated software processes" (Barker, 2005). LOM consists of nine categories: general, life cycle, meta-metadata, technical, educational, rights, relation, annotation, classification, and 77 items.
- ***Dublin Core*** is an interoperable online metadata standard provided by Dublin Core Metadata Initiative (DCMI) to combine metadata vocabularies of different metadata standards and to provide metadata vocabularies for the Linked Data cloud and Semantic Web. The Dublin Core content (concepts) are labeled by coverage, description, type, relation, source, subject, and title. With respect to data of intellectual property and instantiation, 15 data elements are identified by DCMI (Hillmann, 2005). Dublin Core has some overlaps with the LOM (Barker, 2005). The main difference between LOM and Dublin Core is their purpose, i.e. the former is the standard for learning objects, and the latter is the standard to address the problem of resource discovery (Harman & Koohang, 2007).
- ***SCORM*** is an e-learning system standard to eliminate redundant content and envision a "just in time concept" (Harman & Koohang, 2007) developed by Advanced Distributed Learning (ADL). In the recent version of SCORM, the learner's progress can be tracked through the sequence of learning objects (Becta, 2005) (Edi Nugroho, et al., 2016).

2.4.3 Discussion on Doman Specific Ontologies

Considering the discussion on CD- and Educational-Ontologies, one may define two distinctive focal points. On the one side, the focus of the CD-Ontologies is on the competence and/or skill needed in an organization by employees that enables them to perform their activities, roles, or tasks. On the other side, the focus of Educational-Ontologies is on the learning process, learning content, and learning objective. Neither type of ontology addresses whether (or not) the KSCs required to perform a task are supplied by educational systems. Thus, to analyze the balance between what is required by WoW and what is supplied by WoE (i.e. both referring to KSCs), it is important to associate task and learning units via KSC, which is modeled in the present thesis by the Job-Know Ontology (cf. Chapter 5).

Another limitation of the reviewed ontologies is the scope extent, which is restricted to skills required by an organization and/or possessed by an individual as a job seeker and/or an employee to figure out the gaps and needs. However, regardless of a specific organization or skill of an individual, there is a need to specify:

- whether the curricula designed by VET systems (to qualify learner to be able to perform a specific job, e.g. nursing) meets the requirement of the labor market, or
- the curricula taught to overqualified/underqualified learners, who are potential job holders, at the end of the learning process.

Through this analysis, it becomes obvious whether the potential employees, who are graduated in a specific VET field, are competent to perform the job or not. This analysis is person-independent and is for figuring out whether or not the learning outcomes of the curricula of the field meet the requirements of the labor market. The Job-Know Ontology is modeled to respond to this need using an ontology-based semantic reasoning approach (cf. Chapter 6).

3 Job-Know Ontology Framework

3.1 Overview

The present chapter discusses the modeling of the Job-Know Ontology and elaborates on using the proposed methodology for developing the T-Box, domain-independent and populating the A-Box of the Job-Know Ontology for a specific domain. To clarify the objectives of the Job-Know Ontology from the user perspective certain motivating scenarios are described (cf. Chapter 3.2) and, based on them, related competence questions which reveal the outcomes expected from the resultant ontology are defined (cf. Chapter 3.3). The meta-model of the Job-Know Ontology is also discussed (cf. Chapter 3.4). Moreover, knowledge resources, which can be non-ontological and/or ontological and their characteristics are described (cf. Chapter 3.5). Then the methodology of developing T-Box and populating A-Box of the Job-Know Ontology is elaborated (cf. Chapter 3.6). Finally, the ontology development team, which includes an engineering team and a domain team, are introduced and their roles in developing the Job-Know Ontology are discussed (cf. Chapter 3.7).

3.2 Motivating Scenarios

The Job-Know Ontology is mainly developed based on three motivating scenarios which are described below. The scenarios elaborate on the needs of WoW and WoE and, more importantly, how and why these two worlds should communicate with each other and consequently shape the WoC.

Imagine Jana is an employer who works in a position of team leader in an organization. Jana may face different types of *skill imbalance problems* which are defined as scenarios below:

Scenario I - KSCs possessed are less than KSCs required: Jana recently recruited new employees who had just graduated in a specific field from different VET institutions (national and international ones). After a while, Jana recognized that the performances of the novice employees, just hired, are not as expected. She organized meetings with them to discuss what is expected and to hear the thoughts of the employees. She found that the employees did not (fully) possess the required KSCs shown as blue diamonds in Figure 4. In principle, they required these sorts of KSCs to perform their tasks, however, they had not learned them in the VET institutions. In this case, the employees and employer suffer the so-called ***skill imbalance problem***. The employees possess a level of KSCs from learning in the field(s) shown as orange diamonds in Figure 4, but they are not competent to perform the assigned tasks. This means that some of the KSCs required by the employer, shown as purple diamonds in Figure 4, are not matched to the KSCs possessed by the employees, due to the gap, shortage, surplus, and obsoleteness in learning outcomes. Obviously, Jana wants to hire more competent employees, who are ready for work and have already learned the KSCs required.

⇒ **Occurrence:** KSCs of newly graduated employees are an imbalance due to the gap, shortage, surplus and obsoleteness in learning outcomes.

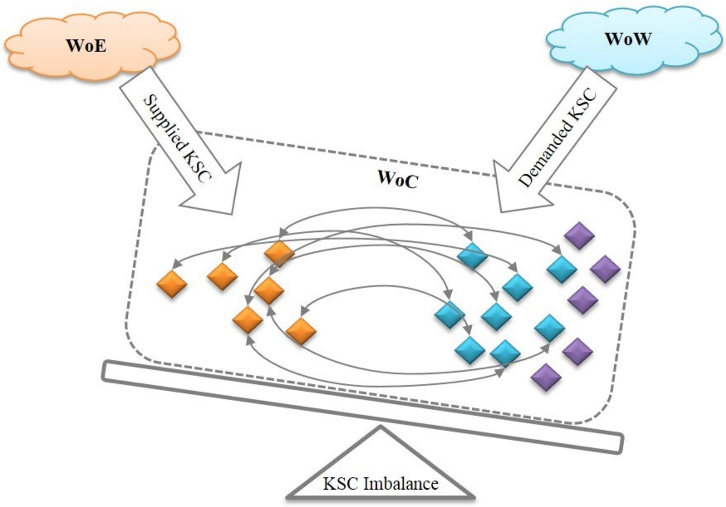

Figure 4 KSCs possessed are less than KSCs required

Scenario II - KSCs required are increased over time: Jana has proficient employees. She recently noticed a decrease in their performances. Jana organized meetings and discussed the issue with them. She found that employees suffer from a gap and shortage of numerous KSCs required to work with newly purchased technologies and to provide new services. This means KSCs required by the employers are not in balance with KSCs possessed by the employees. As illustrated in Figure 5, the so-called ***skill imbalance problem*** occurred, in this case, due to the gap and shortage of the lifelong learning outcome, which should be obtained in the learning process on the job. Some new/emerging KSCs, which are shown as green diamonds in Figure 5, are not matched to the existing KSCs possessed by the employees. The employees, therefore, need to obtain the new sort of KSCs to be able to perform the assign tasks competently. Obviously, Jana wants the employees to possess the new/emerging KSCs required to perform new tasks and to cope with changes in the tasks over time.

⇒ **Occurrence:** KSCs of proficient employees are an imbalance due to the gap, shortage, surplus and obsoleteness of KSCs to deal with new technology/service.

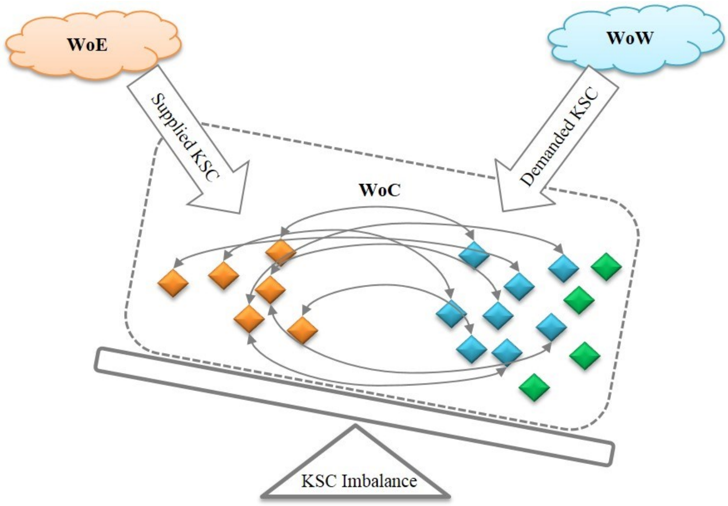

Figure 5 KSC required are increased over time

Scenario III - KSCs possessed are more than KSCs required: Jana has an employee who is always dissatisfied. They set a meeting and Jana recognized that this employee is over-qualified as she graduated abroad. So, the KSCs she gained by learning in the VET institution, are more than is required for this job. As illustrated in Figure 6, the so-called ***skill imbalance problem*** occurred in this case due to the surplus of learning outcome supplied in comparison to the required KSCs. The red diamonds in Figure 6 show the surplus learning outcomes, which are not matched to the KSCs required to fulfill the assigned tasks.

⇒ **Occurrence:** KSCs of the employee are imbalanced due to the surplus and obsoleteness of KSCs possessed.

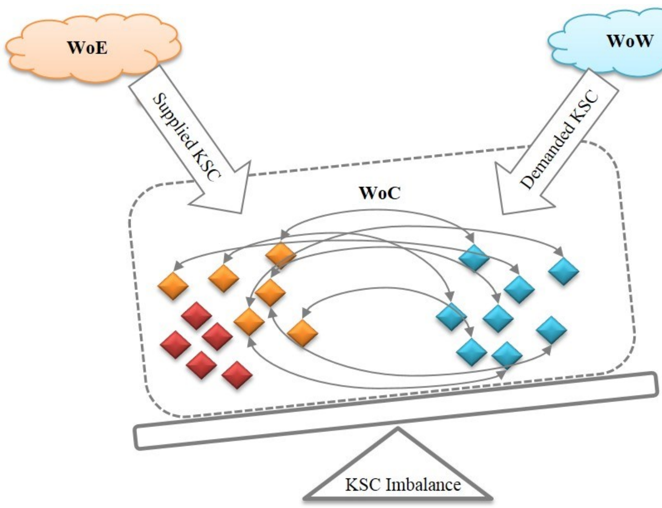

Figure 6 KSCs possessed are more than KSCs required

The first scenario states that the WoW demands should be supplied by the WoE in right time, otherwise the KSC imbalance problem occurs. The second scenario addresses the WoW demands that evolve over time, thus, WoE should update the outcomes based on the needs of the WoW and transmit it through lifelong learning. In other words, not only inappropriate VET but also a lack of continual VET, either on the job or off the job, may cause skill imbalance. The third scenario addresses the other side of the skill imbalance problem in which either the WoW has not anticipated the changes in the curriculums over time, or the job description was prepared based on coverage of KSCs taught in regional or national curriculums rather than international ones. The aforementioned scenarios identify the need for a systematic approach and related assistance tools in:

- **Allocating job-specific KSCs**: To perform a task, a set of KSCs are demanded. In this way, there must be a systematic approach to identify KSCs demanded in accord to tasks of a job.
- **Clustering job-specific KSCs:** The demand degree of KSCs required to perform a job in different organizations is dissimilar. Hence, there must be a systematic approach to identify the demand degree of KSCs for performing tasks of a job in different organizations.
- **Identifying job-specific learning outcomes:** To possess KSCs via learning the units taught in a specific learning field, there must be a systematic approach to identify the learning outcomes.
- **Clustering specific learning outcomes:** The supply degree of varieties of learning units, which should be learned to qualify the learners to possess a learning outcome, is different. Thus, there must be a systematic approach to identify the supply degree of learning units for possessing KSCs supplied by WoE.
- **Discovering KSC imbalance problems in WoC:** There must be a systematic way of identifying KSCs imbalance in a company/enterprise in regional, national, or at international level, which is rooted in supplied KSCs and changes in evolving environments. However, it should be independent of the performance of individuals.
- **Overhauling and Modernizing of KSCs:** Finally, there must be a systematic way to identify what KSCs are demanded over time to be able to supply right KSCs in right time.

3.3 Competency Questions

The term competency question (CQ) (Grüninger and Fox 1995), (Katsumi and Grüninger 2010) identifies the outcomes of Job-Know Ontology. The CQs aim to specify what can be inferred and reasoned by the Job-Know Ontology. The CQs of the Job-Know Ontology are detailed in three groups, namely: i) CQs for WoW, ii) CQs for WoE, and iii) CQs for WoC, which are described respectively:

I. CQs related specifically to WoW domain (which are examined in Chapter 4):

- **CQ-1:** What sort of KSCs are demanded to perform a task?
- **CQ-2:** To what extent is performing a task dependent to a specific KSC?

II. CQs related specifically to WoE domain (which are discussed in Chapter 5):

- **CQ-3:** What learning unit(s) can qualify an individual to possess a specific learning outcome?
- **CQ-4:** To what extent is a learning unit capable of qualifying an individual to obtain a specific KSC?

III. CQs related specifically to WoC domain (which is studied in Chapter 6):

- **CQ-5:** To what extent is a learning unit the right qualified enabler for a job?
- **CQ-6:** What type of transition is required to move to or to keep the balance state?

3.4 Meta-Model of Job-Know Ontology

There are two ways to approach KSC: i) the perspective of WoE, where KSC is considered as learning outcome which should be provided and supplied, and ii) the perspective of WoW, where KSC is demanded to perform a job. There is no conflict between these two perspectives, however depending on the stakeholders (i.e. learner, educator, educational institution, employer, job designer), one way might be focused on more than the other. In fact, to define the WoC as the communication channel, the two perspectives should be investigated together.

With respect to the WoE perspective, KSC is defined as an umbrella term for "learning outcomes" (cf. Chapter 5.3 – Table 12), which qualifies learners to be able to perform a specific job. While according to WoW, KSC is what enables employees to perform their jobs competently (cf. Chapter 4.3 – Table 7). As Figure 7 illustrates, the meeting point is "what is supplied by WoE" and "what is demanded by WoW", which is placed in the WoC and should be in balance to tackle the skill imbalance problems, particularly in an evolving job market.

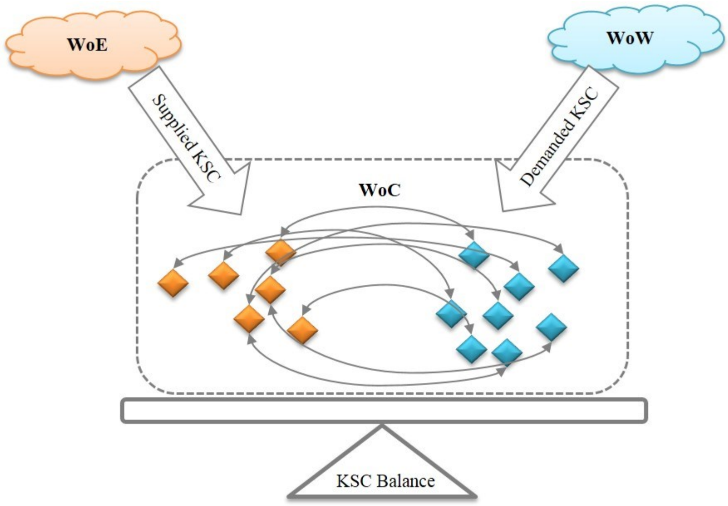

Figure 7 WoC in Balance

To semantically represent WoE, WoW and WoC towards analyzing whether or not KSC supply and demand is in balance, an ontology is developed - the so-called Job-Know Ontology. The Job-Know Ontology consists of two domains of WoW and WoE that connect to each other based on the principles of supply and demand. In other words, these two worlds meet when i) a set of KSCs are demanded by the WoW (which should be supplied by the WoE) for performing a job, and/or ii) for learning a set of KSCs for a job which are taught based on the demands of the WoW. The WoC is defined at the matching point of the WoW and WoE.

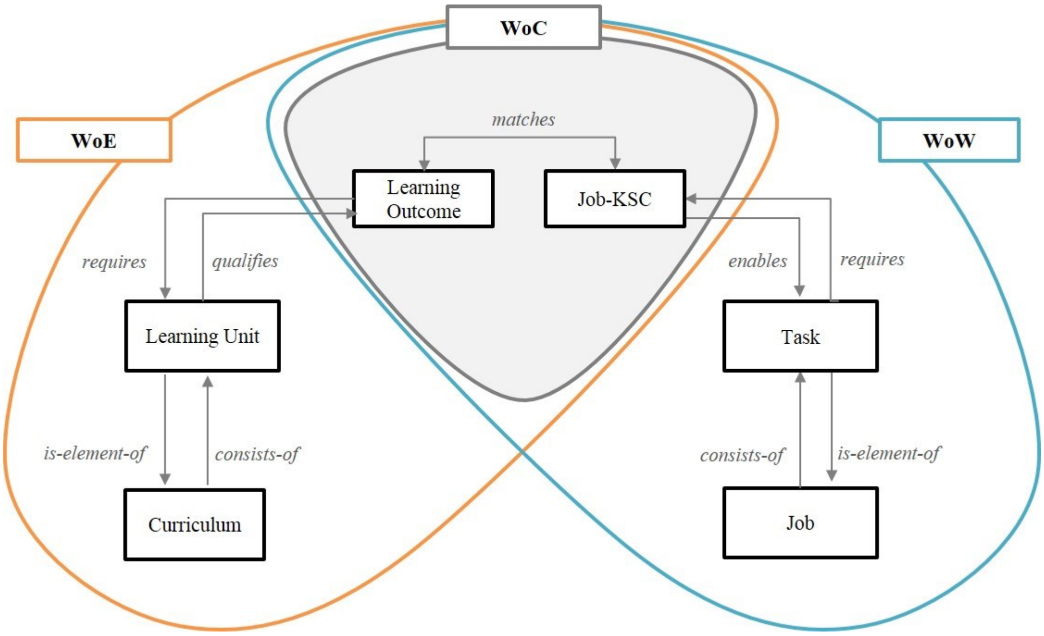

Figure 8 Meta-Model of Job-Know Ontology

The meta-model of Job-Know Ontology is shown in Figure 8. The WoW domain asserts the jobs, their tasks, and KSCs demanded to perform the jobs (cf. Chapter 4). The WoE domain, specifically VET, asserts the learning fields, learning units and learning outcomes (cf. Chapter

5). Finally, the WoE and WoW domains are matched via KSC conversion table (cf. Chapter 6.3 – Table 15). The WoC is apparent, regardless of who supplies the demand and who demands the supply, and focuses on what is supplied and what is demanded.

In other words, the meta-model represents how the WoW (specifically a job) and the WoE (specifically a curriculum of a learning field) communicate to figure out whether or not learning the given curriculum is satisfactory to possess the required KSCs to perform the given job.

The Job-Know Ontology as a knowledge-base consists of T-Box and A-Box, which are modeled, formalized, and finally populated for a specific job and education domain. As the abstraction of Job-Know Ontology is a domain-independent model which is not associated with any instance (job and knowledge domain), firstly the T-Box including the concepts and the relations is developed, and then the A-Box of the ontology is populated for a specific job and education. In this way, we established a methodology, which consists of two parts to develop T-Box and A-Box, to be introduced in Chapter 3.6. Before elaborating the methodology, the knowledge resources, which should be taken into account to develop the Job-Know Ontology, are discussed in the following sub-chapter.

3.5 Knowledge Resources

A knowledge resource is either a source or supply of knowledge, which can be documented or held by human. The knowledge resources to develop an ontology are distinguished into ontological and non-ontological resources (Suárez-Figueroa, Gomez-Perez and Fernandez-Lopez 2011). One of the objectives of developing an ontology is increasing the level of usability of resources. So, it is very probable that there is an ontology(s), which can be reused to develop a new ontology.

Both types of the aforementioned resources consist of characteristics which include (Maier 2007):

- **Formality:** which defines how much knowledge is institutionalized, approved and distinguished into informal and formal knowledge resources.
- **Accessibility:** which addresses how much knowledge, is electronically accessible and distinguished into electronically accessible and electronically inaccessible knowledge resources.
- **Externalization:** which states how much knowledge is externalized, documented and distinguished into explicit and implicit knowledge resources (Wijnhoven 2006).

- **Medium:** which stresses dependency of knowledge to the owner. Medium is distinguished into person-independent (i.e. object) and person-dependent (i.e. expert).

In the following the ontological and non-ontological knowledge resources are explained based on the four characteristics defined above.

Ontological Resource - the formality dimension divides the ontological resources into informal ontology (i.e. the ontology which is available in a conceptual level), and formal ontology (i.e. the ontology which is codified and evaluated). The accessibility dimension distinguishes between the electronically accessible ontological resources (i.e. the existing informal ontology which is digitalized and the formal ontology), and the electronically inaccessible ones (i.e. the existing informal ontology which is available on paper). The externalization dimension distinguishes the resources to explicit knowledge (i.e. the knowledge which is documented, however, the level of details and maturity should be examined). The medium of ontological resources is person-independent; this means that either informal or formal ontology should be reusable without needing a person from the team that developed the ontology. Table 3 summarizes the above discussion.

Non-Ontological Resources - the formality dimension divides the non-ontological resources into: i) informal documents, such as documents, and videos, which have not been approved, and therefore, the reliability of the document is under question, ii) formal documents i.e. the document has been evaluated and approved, and iii) expertise which refers to knowledge of expert. Expertise should be categorized as an informal knowledge resource which is not yet documented, however, the knowledge is approved by the expert her/himself, even though it may require fine-tuning and purification to reach a certain maturity level. The accessibility dimension distinguishes between the electronically accessible non-ontological resources (i.e. the documents which are digitalized), and the electronically inaccessible ones (i.e. the documents which are available on paper and the knowledge of experts, or which are not accessible electronically or on paper). The externalization dimension distinguishes the non-ontological resources to explicit knowledge (i.e. the contents, which are documented), and implicit knowledge (i.e. knowledge of experts, which are not documented). The medium of non-ontological resources is person-independent (e.g. documents), and person-dependent (e.g. knowledge of expert). The non-ontological resources are mainly (re)used in the Conceptualization phase-DP1 (cf. Chapter 3.6.1). Table 3 summarizes the aforementioned discussion.

Table 3 Characteristics of Ontological and Non-Ontological Knowledge Resources

		Ontological Resources		***Non-ontological Resources***	
Characteristics	***Types*** / *Dimension*	***Informal Ontology***	***Formal Ontology***	***Explicit Resources***	***Implicit Resource***
1. Formality	*1.1.Formal*	-	√	√	-
	1.2.Informal	√	-	√	√
2. Accessibility	*2.1.Electronically*	√	√	√	-
	2.2.Non-Electronically	√	-	√	√
3. Externalization	*3.1.Implicit*	-	-	-	√
	3.2.Explicit	√	√	√	-
4.Medium	*4.1.Person-dependent*	-	-	√	√
	4.2.Person-independent	√	√	√	-

3.6 Methodology of Developing Job-Know Ontology

The methodology to develop the Job-Know Ontology has two parts. The first refers to the development of the T-Box of the ontology, which occurred once to create the skeleton of the Job-Know Ontology based on the meta-model (cf. Chapter 3.4). The latter part is to populate and instantiate the A-Box for a specific job (e.g. nursing job) and education (e.g. nursing education). This occurs whenever a specific new job/education is requested to populate the Job-Know Ontology. The following sections 3.6.1 and 3.6.2 discuss the methodology for developing T-Box and A-Box, respectively.

3.6.1 Methodology to Develop T-Box

The methodology to develop T-Box of the Job-Know Ontology includes three developing plans (DPs), which should be applied in sequence or in parallel (cf. Figure 9). These DPs are described in the following:

- **DP-1** is the core plan to develop the Job-Know Ontology, which includes four phases, namely: i) *Specification*, ii) *Conceptualization*, iii) *Formalization*, and iv) *Implementation*.
- **DP-2** has two phases: i) *Searching & Selection,* and ii) *Reuse & Reengineering*. The first phase, *Searching & Selection*, occurred within the Specification phase in DP-1 to identify the resources which should be reused to develop the Job-Know Ontology. The resources might be non-ontological and/or ontological (cf. Chapter 3.5). The selected resources are then retrieved and transformed in the *Reuse & Reengineering* phase to extract the required knowledge. This phase occurs within the *Conceptualization* phase of DP-1. Notably, the

selected ontological resources can be available in different development levels (i.e. conceptual, formalized or implemented ontology) (Suárez-Figueroa, Gomez-Perez and Fernandez-Lopez 2011). Thus, the selected ontology should be reengineered from the actual level (e.g. implemented level) to the required level (e.g. conceptual level) to become (re)usable for the Job-Know Ontology.

For example, Ontology O_1 exists in a format of OWL file, however, it does not quite fit for our purpose, therefore, there is a need to reengineer O_1 to transform it into the concept level and then to reuse some part of the ontology. In addition, there can be more than one ontology, which can be considered as resources to develop the resultant ontology, so these ontologies should be aligned and merged.

- **DP-3** has two phases of i) *Restructuring* and ii) *Localization*. Within the *Restructuring* phase, the knowledge resources (either ontological or non-ontological) are modified to respond to the ontology requirements. Further, within the *Localization* phase, the resources are translated into the language(s) specified in requirements to provide the ontology requirements specification document (ORSD). These two phases are independent and there is no need to apply both or to follow in sequence. DP-3 occurs within the *Reuse & Reengaging* phase of DP-2.

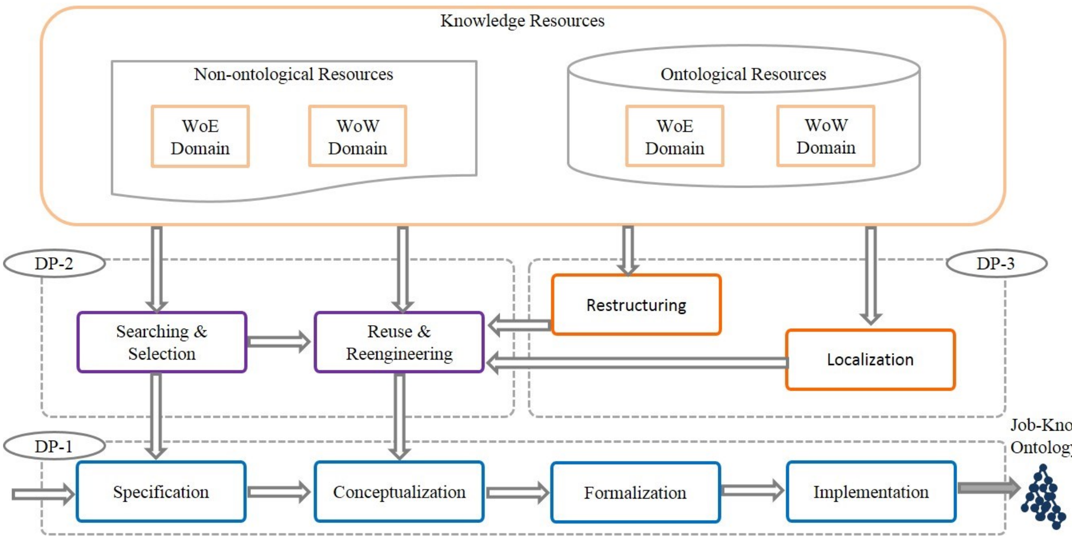

Figure 9 Methodology to develop T-Box of Job-Know Ontology adopted from (Khobreh, Ansari and Fathi, et al. 2016)

Moreover, the support activates are needed to acquire knowledge, document the process and the results, evaluate the ontology within the process of development and also validate the resultant ontology (Suárez-Figueroa, Gomez-Perez and Fernandez-Lopez 2011).

In the following, the input, output and the activities of the phases are described in detail.

Specification Phase - The first phase of DP-1 is specification of the ORSD. The inputs of the specification phase are "Motivating Scenarios" and "Competency Questions" as discussed in Chapter 3.2 and 3.3, respectively. The outputs of this phase are "Scope", "User", "Knowledge Resource", and "Methods of Data Collection" (cf. Table 4). Figure 10 depicts the inputs and outputs of the specification phase.

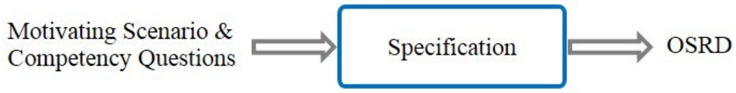

Figure 10 Inputs and Outputs of Specification Phase

Table 4 includes the key points, which should be specified by the ontology development team, according to, i) the scope of the job and VET domains, ii) the user of the Job-Know Ontology, who might be in macro and/or micro level(s), iii) the knowledge resources either ontological or non-ontological, and iv) the methods to collect the data from job and VET domains.

Table 4 Specification of Scope, User, Knowledge Sources and Data Collection Model of Job-Know Ontology

Area	***Domain***	***Specification***
Scope	*WoW*	*Occupation standards, job descriptions and specification in national level (e.g. Germany) and international level (e.g. the European Union).*
	WoE	*Educational standards, the learning fields and their learning units defined in the national level (e.g. Germany) and international level (e.g. European Union).*
User	*WoW*	*Employee, employer, job designer, and WoW policy maker*
	WoE	*Learner, parent, teacher, curriculum designer, and WoE policy maker*
Knowledge Resources	*WoW*	*It is specified in Table 5.*
	WoE	*It is specified in Table 5.*
Methods of data collection	*WoW*	*Interview, observation, concept map, and matrix (cf. Chapter 4.5)*
	WoE	*Interview, observation, concept map, and matrix (cf. Chapter 5.5)*

Within the *Specification* phase, the *Searching & Selection* phase of DP-2 is applied to identify knowledge resources. The specifications of the WoW domain, as well as the WoE domain, are detailed respectively in Chapter 4.2 and Chapter 5.2.

Searching & Selection phase – As illustrated in Figure 9 and discussed in Chapter 3.5, there can be two types of knowledge resource, namely non-ontological and ontological (cf. Figure 11). Within this phase, the knowledge analyst with the support of the knowledge provider (cf. Chapter 3.7) searched for the non-ontological resources from different sources such as ISCO[9], ISCED[10], WHO[11], CEDEFOP[12], UNESCO[13]. In addition to ontological resources, the keywords of "competence", "education", "job", "labor market", and "curriculum" have been searched in repositories of WATSON[14] and Swoogle[15], which are specifically for sharing resultant ontologies. Besides, the knowledge analyst searched for the scientific articles, which discuss the topic and are accessible in scientific repositories such as Google Scholar[16], Science Direct[17], Springer[18], and IEEE Xplore[19].

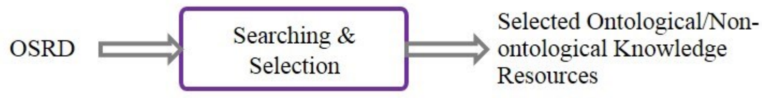

Figure 11 Input and Output of Searching & Selection Phase

In particular, there is no qualified and implemented ontology found in the repositories of WATSON and Swoogle. However, there are numbers of scientific articles, which have conceptualized and formalized the ontologies in the interest of domain. These are selected by the knowledge analyst and knowledge provider. The ontological resources which are reused for the WoW domain are discussed in Chapter 2.4.2 and for WoE in Chapter 2.4.3. Notably, there is no implemented ontology, which is essential to merge/integrate into the Job-Know Ontology. Table 5 shows the ontological and non-ontological resources, which are reused to conceptualize the T-Box of the Job-Know Ontology.

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[9] http://www.ilo.org/global/publications/lang--en/index.htm (accessed on 07.07.2017)

[10] http://www.uis.unesco.org/ (accessed on 07.07.2017)

[11] http://www.who.int/publications/en/ (accessed on 07.07.2017)

[12] http://www.cedefop.europa.eu/en/publications-and-resources (accessed on 07.07.2017)

[13] http://uis.unesco.org/ (accessed on 07.07.2017)

[14] http://watson.kmi.open.ac.uk/WatsonWUI/ (accessed on 07.07.2017)

[15] http://swoogle.umbc.edu/ (accessed on 07.07.2017)

[16] https://scholar.google.com (accessed on 07.07.2017)

[17] http://www.sciencedirect.com (accessed on 07.07.2017)

[18] http://www.springer.com (accessed on 07.07.2017)

[19] http://ieeexplore.ieee.org (accessed on 07.07.2017)

Table 5 Knowledge Resources for Job-Know Ontology

Domains	***Ontological***	***Non-ontological***
WoE	*Curriculum ontology* (British Broadcasting Corporation (BBC) 2013) *Learning outcome ontology* (Kalou, et al. 2012)	*ISCED* (UNESCO Institute for Statistics 2014) *EQF* (European Commission 2010) *DQR (German)* (German Qualifications Framework Working Group 2013)
WoW	*Skill ontology discussed in* (Biesalski and Abecker 2005) *Professional learning ontology developed in* (Schmidt and Kunzmann 2007) *HR-ontology defined in* (Dorn, Naz and Pichlmair 2007) *Skill ontology* (Fazel-Zarandi and Fox 2012)	*ISCO* (International Labour Office 2012) *KldB (German)* (Bundesagentur für Arbeit 2011), (Bundesagentur für Arbeit 2011) *ESCO* (European Union 2013) *DISCO* (Markowitsch and Plaimauer 2009)

Conceptualization Phase – This phase is for the elaboration of the ORSD to identify the fundamental concepts. Therefore, "terminology/glossary" of the domains and "relation" between the concepts are defined within this phase. The result of this phase is the informal/conceptual ontology. Referring to the NeOn definition, the *Conceptualization* phase is independent of the tools that will be used for implementing the ontology (Suárez-Figueroa, Gomez-Perez and Fernandez-Lopez 2011). The input and outputs of this phase are shown in Figure 12.

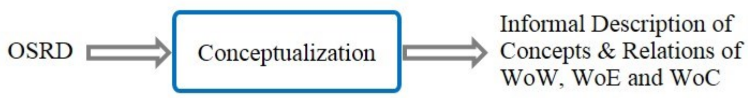

Figure 12 Input and Output of Conceptualization Phase

To conceptualize the ontology, a concept map, which is a graphical tool for representing concepts (knowledge), is used. The concept map consists of a circle to represent the concept, and lines linking to concepts and named by terms specifying the relationship between the two concepts (Novak 2010).

The conceptualization of the WoW, the WoE and the entire ontology – all of which will be discussed in Chapter 4.3 and Chapter 5.3. To conceptualize and elucidate the informal description of the concepts and their relations, the *Reuse & Reengineering* phase of DP-2 is applied.

Reuse and Reengineering Phase – *Reuse & Reengineering* phase is used to retrieve, analyze, and transform the selected resources (ontological/non-ontological), which may not completely fit with ORSD. Within this phase, the resources may pass the *Restructuring* and *Localization* phases of DP-3 adapted to the best-fit conceptual model for the Job-Know Ontology. The input of this phase is knowledge resources and the output is the resources which are made ready for using in the *Conceptualization* phase (cf. Figure 13).

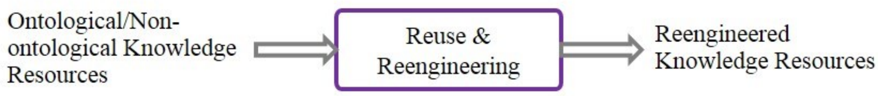

Figure 13 Input and Output of Reuse and Reengineering Phase

Restructuring Phase – Within this phase, depending on the needs identified by the knowledge analyst and domain expert, three activities may occur on the informal ontology which are: i) pruning to exclude unnecessary concept/role, ii) extending to add new concept/role, and iii) modifying to change the name and/or place of concept/role. The input of this phase is informal ontology and the output is restructured ontology (cf. Figure 14).

Figure 14 Input and Output of Restructuring Phase

Localization Phase – The concepts/roles extracted from the knowledge resources may be in different natural language(s), which do not meet the ORSD. So, this data should be translated to the natural language specified for the resultant ontology. This phase occurs within the *Conceptualization* phase of DP-1 to provide the knowledge in a requested natural language. The input of this phase is an informal/formal ontology which is not in a requested language and the output is the ontology in a requested language (cf. Figure 15).

Figure 15 Input and Output of Localization Phase

Formalization Phase - Within this phase the T-Box of the Job-Know ontology is formalized based on the concepts and roles conceptualized in the *Conceptualization* phase. The input of the phase is an informal ontology, and the output is a formal ontology. Figure 16 shows the inputs and outputs of the formalization phase.

Figure 16 Input and Output of Formalization Phase

The T-Box of WoW domain and WoE domain are formalized, respectively in sections 4.4. and 5.4.

Implementation Phase - Finally the formal ontology is codified in a machine-readable format and the result is stored as an OWL[20] file. To implement the ontology the free open-source editor, Protégé[21], which is a well-known editor available in desktop and web-based editions, is used. Protégé allows users to model the concept as "Class", the role as "Object property" and "Data property" where data property relates an individual to a data type (e.g. an integer), and the individual (an instance of a class) as "Individual" (Noy and McGuinness 2001). Protégé provides several reasoned mechanisms, namely; ELK (Kazakov, Krötzsch and Simancik 2012), Pellet (Sirin, et al. 2007), Hermit (Horrocks, Motik and Wang 2012), jcel (Mendez 2012), - and the user may select one of them. Moreover, Protégé has plug-ins, which provide visualization of the classes, roles and individuals using visual diagrams.

The input of implementation phase is the formal ontology provided by the previous phase and the output is the implemented ontology. Figure 17 shows the input and output of the implementation phase.

Figure 17 Input and Output of Implementation Phase

3.6.2 Methodology to Develop A-Box

The Job-Know Ontology is domain-independent, therefore, the T-Box (i.e. concepts and roles) is developed, regardless of the individuals of the domains. In order to populate and instantiate the individuals of the Job-Know Ontology for a specific job and education, the A-Box is developed. As illustrated in Figure 18, to develop the A-Box of the Job-Know Ontology three DPs, which are described earlier, are needed.

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[20] Refers to Web Ontology Language

[21] http://protege.stanford.edu/ (accessed on 07.07.2017)

The focus of developing the T-Box is on creating the skeleton of the ontology; therefore, the outputs of the phases provide the concepts and roles of the ontology. In contrary, the focus of developing the A-Box is on filling the concepts of the ontology with the individuals extracted from the specific job and education. Notably, the activities of the phases are the same but the focal points are different, i.e. former on the concepts and roles, and later on the individuals. Therefore, instead of *Conceptualization* and *Formalization* phases, the *Instantiation* Phase, which includes the activities mentioned below, is defined.

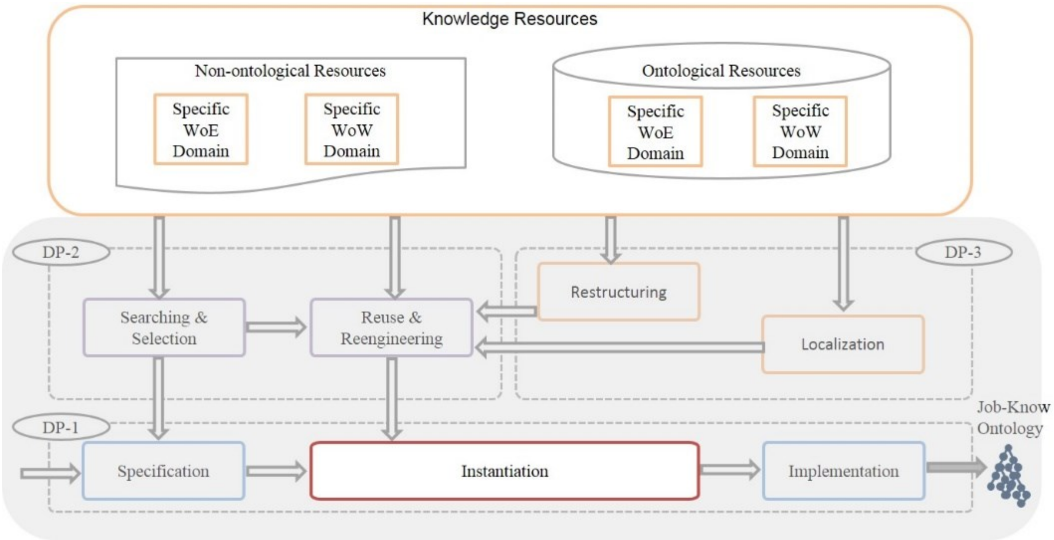

Figure 18 Methodology of Populating A-Box of Job-Know Ontology - Instantiation Phase

Instantiation Phase - Within the *Instantiation* phase, the learning units, job tasks, learning outcomes, Job-KSCs and role between them are identified and asserted. Moreover, the conversion table of KSCs (cf. Chapter 6.3 – Table 15), WoW matrices (cf. Chapter 4.5) and WoE matrices (cf. Chapter 5.5) are established. In addition, the knowledge provider and knowledge analyst are involved in this phase to provide the knowledge required as the individuals (e.g. a nursing task) of the ontology. Figure 19 shows the activities, which should be fulfilled within this phase.

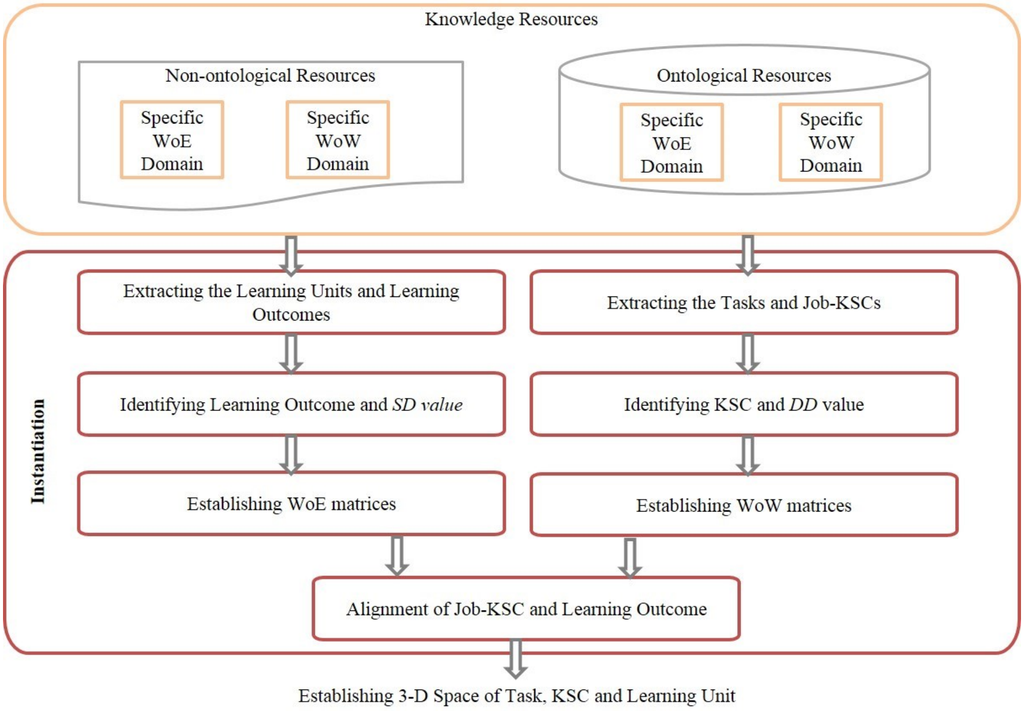

Figure 19 The Activities of the Instantiation Phase marked in Red

The ontology development team should also align the WoW and WoE from their meeting point, which is KSC. To do so, knowledge providers from both domains should work collaboratively to identify how Job-KSCs correspond to the learning outcomes and instantiate new KSCs or reuse the existing ones (cf. Chapter 6.3).

3.7 Ontology Development Team

To develop and populate the Job-Know Ontology, the ontology development team (ODT) should be built up from the beginning and prior to initiating any activity. ODT includes the engineering team (ET) and domain team (DT), who need to collaborate from the beginning of the development process till the end. However, their involvement is not the same over time (cf. Figure 20).

The ET distinguishes the two roles of knowledge analyst (KA) and ontology engineer (OE). The main activity of this team is the acquisition of knowledge, conceptualization, and implementation of the knowledge-base, which is ontological in our case. The role of KA and OE can be taken by one person depending on the size of the project and availability of competent human resources.

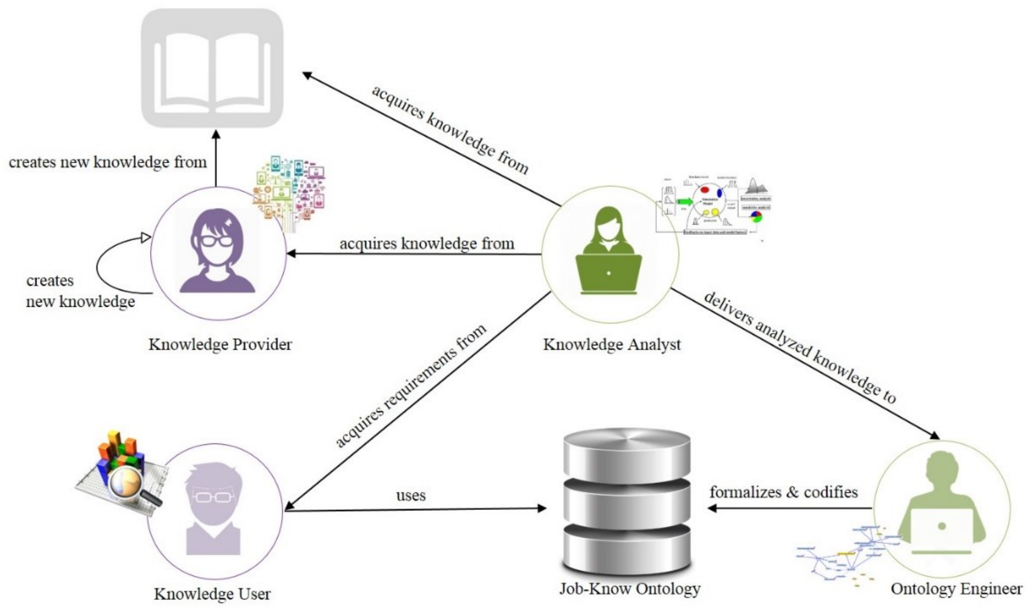

Figure 20 Ontology Development Team

As illustrated in Figure 20, KA acquires explicit and/or implicit knowledge from various knowledge resources. The knowledge resources, which are required to build up the Job-Know Ontology, are available in ontological and non-ontological forms (cf. Chapter 3.4). Within the process of ontology development, the KA is involved in certain phases and is responsible for four activities which are noted below:

- To specify the requirement of the user to provide appropriate knowledge for conceptualizing the informal ontology (as a part of Specification phase-DP1).
- To search, assess and select the knowledge resources (as a part of Specification phase-DP1).
- To analyze and acquire appropriate knowledge from them (as a part of Conceptualization phase-DP1).
- To retrieve and transform a conceptual model of an existing ontology into a new one (i.e. more correct and a complete conceptual model), which satisfies the requirement specified in the Specification phase (as a part of Reuse & Reengineering phase- DP2). Notably, depending on the development level of the ontological resources (i.e. it is available as conceptual, formalized, or codified ontology) and correlation of the ontology found and ontology aimed for, the involvement of KA is different. In other words, if the ontology is available in a formalized and codified level, then the first task of the OE is to reengineer the existing ontology to the level appropriate to extract required knowledge.

The main activity of OE is formalizing and codifying the ontology, however, (s)he is also involved in the activities mentioned below:

- To assess whether or not the searched ontologies are reusable (as a part of Specification phase-DP1).
- To restructure (i.e. exclude, include and/or modify) the concepts and roles of the existing ontological resources to fit with the purpose (as a part of Restructuring phase-DP3).
- To formalize the conceptual ontology provided by KA (as a part of Formalization phase-DP1),
- To perform the technical activities through codifying the ontology, i.e. computable models according to the syntax of a formal representation language (as a part of Implementation Phase-DP1).

The DT includes the knowledge provider (KP) and knowledge user (KU). The KP possesses and/or creates the domain knowledge needed to develop the ontology (Schreiber, Akkermans, et al. 2000). The KP in collaboration with the KA provides the required domain-specific knowledge and validates the ontology which is conceptualized by the ET. The DT is mainly involved in Specification and Conceptualization phases (cf. Chapter 4.2 and 4.3 for WoW and Chapter 5.2 and 5.3 for WoE). Notably, the Job-Know Ontology includes two domains of WoW and WoE, therefore, the DT approaches the tasks of knowledge provision and validation from both sides.

In the following, the activities which the KP should perform are described:

- To search, assess and select the knowledge resources (as a part of Specification phase-DP1).
- To analyze and acquire knowledge from the resources (as a part of Conceptualization phase-DP1).
- To support the KA to provide the required knowledge (as a part of Conceptualization phase-DP1).
- To support OE to restructure the selected ontologies to make them fit with the purpose (as a part of Restructuring phase-DP3).
- To translate the existing knowledge resources to the natural language specified in the ORSD (as a part of Localization phase-DP3).

- To validate the informal and formal ontology contextually (as a part of Conceptualization and Implementation phases-DP1).

Moreover, the tasks and activities of KU in the process of ontology development are listed below:

- To specify and explain their needs (as a part of Specification phase-DP1).
- To evaluate the translation of the existing knowledge resources to the natural language specified in the ORSD (as a part of Localization phase-DP3).
- To support KA and KP to provide required knowledge (as a part of Conceptualization phase-DP1).

In particular, depending on the context of ontology development, KP and KU can be one or multiple persons. Table 6 summarizes who should be involved in each activity of the phases discussed above.

Table 6 ODT Involvement to Develop Job-Know Ontology

Box	***Core DP***	***Activity***	***ODT Involvement***
T-Box	*Specification-DP1*	*Specify ontology's scope*	***KA, KU, KP***
		Specify ontology's user	***KA, KU, KP***
		Search for knowledge resources	***KA, KP***
		Assess knowledge resources	***KA, KP***
		Select knowledge resources	***KA, KP***
	Conceptualization- DP1	*Acquire knowledge resources*	***KA, KP***
		Reengineer (non)-ontological resources–DP2	***KA***
		Reengineer ontological resources–DP2	***OE***
		Restructure non-ontological resources–DP3	***KA***
		Restructure ontological resources–DP3	***OE***
		Localize knowledge resources–DP3	***KA, KP***
		Model informal ontology	***KA, OE***
		Evaluate informal ontology	***OE, KA, KP***
	Formalization-DP1	*Formalize formal ontology*	***OE***
		Evaluate formal ontology	***OE***
		Codify resultant ontology	***OE***

Box	***Core DP***	***Activity***	***ODT Involvement***
	Implementation-DP1	*Evaluation resultant ontology*	***OE, KP, KU***
A-Box	*Instantiation-DP1 (A-Box)*	*Extract individuals from specific WoE and WoW domains*	***KA, KP***
		Identify supply and demand degree	***KA, KP***
		Establish WoW matrices (cf. Chapter 4.5), WoE matrices (cf. Chapter 5.5) and KSC conversion table (cf. Chapter 6.3)	***KA, KP***
		Codify the individuals	***OE***

3.8 Summary and Discussion

This chapter discusses the fundamental aspects of the Job-Know Ontology framework, including the motivating scenarios, CQs, meta-model, knowledge resources, the methodology of development of T-Box and A-Box, and finally ODT.

The three motivation scenarios explain why the Job-Know Ontology is needed. The first scenario highlights that the employees should possess required KSCs to perform the assigned tasks. The second scenario addresses that what is learned in WoE should be based on the demands of WoW to hold and/or keep required KSCs in balance. The third scenario states that supplying more KSCs by WoE, which is not demanded by WoW can also cause imbalance problems. The common points that run through these scenarios are to i) identify the demands, ii) design supply in relation to demands, and iii) a need to establish a dialogue channel between WoW and WoE to make and/or keep balance in WoC.

The CQs are defined based on the motivating scenarios that identify the outcome of the Job-Know Ontology. In other words, the results expected by inferring and reasoning of the Job-Know Ontology provide the answers of the CQs. Moreover, CQs target the destination from the beginning, which is identified in light of the scope and user of the ontology.

In order to develop any ontology, there is a need to employ a methodology. There are different ontology methodologies discussed in Chapter 2 and elaborated in detail in Appendix 1-Table 22. To develop the Job-Know Ontology, the present thesis proposes and establishes a new methodology. This methodology is mainly inspired by NeOn methodology (Suárez-Figueroa, Gomez-Perez and Fernandez-Lopez 2011) to define the DPs, and DILIGENT (Pinto, Tempich and Staab 2009) to establish the ODT. The methodology, which is established in this chapter, consists of two parts to develop the T-Box of the ontology and populate its A-Box. The methodology to develop T-Box consists of three DPs, which include the phases: DP1

Specification, Conceptualization, Formalization, and *Implementation* phases, DP2 *Search & Selection* and *Reuse & Reengineering phases* and, DP3 *Restructuring* and *Localization* phases. To develop the A-Box the DPs and all aforementioned phases, except *Conceptualization* and *Formalization,* are applied but with the focus on individuals rather than concepts and relations. Instead of the *Conceptualization* and *Formalization* phases, the *Instantiation* phase is applied to firstly extract the required individuals from the knowledge resources, secondly to identify the detail requirements such as supply and demand degrees, and finally to establish the defined matrices.

In sum, this chapter gives an overview clarifying how the Job-Know Ontology is developed and can be populated in different domains. The WoW and WoE domains of Job-Know Ontology are discussed in Chapter 4 and 5, respectively, in which the demand and supply are formalized. Afterward, the mechanism for building the communication channel between WoW and WoE, known as WoC, is elaborated in Chapter 6.

4 WoW Domain of Job-Know Ontology

4.1 Overview

In the present thesis, WoW is the encapsulation and ontological formalization of a job and related attributes that model it independent of the context in various regional, national, international levels. To be able to perform a job, which includes tasks defined by the employer, the job holder (employee) should possess a set of KSCs. In fact, there is a semantic relation between job, task, and required KSC.

This chapter discusses the systematic way to represent the WoW domain and to provide a knowledge-based mechanism to infer the demands of WoW. The structure of this chapter is based on the four phases of DP-1 described in Chapter 3.7. First, the WoW domain is specified in Chapter 4.2; second, it is conceptualized in Chapter 4.3, and finally it is formalized in Chapter 4.4. Later, the results (instances of the WoW) are presented in Chapter 7 by exemplifying the domain-specific use-case of nursing.

4.2 Specification of WoW Domain

As stipulated in Chapter 3.6.1. *Specification*-DP1, the scope of the Job-Know Ontology to define the three concepts of Job, Task, and KSC is based on the International Standard of Classification of Occupation (ISCO), and specifically the German Standard of Classification of Occupation (KldB)[22]. In the following, these two international and national standards are described.

4.2.1 International Standard of Classification of Occupation (ISCO)

The International Standard of Classification of Occupation (ISCO)[23] is based on the two concepts of job and skill. At a glance, a job is a set of tasks and an occupation is set of jobs, in which their main tasks have a high degree of similarity. Skill is defined as the ability to perform the tasks of the jobs. ISCO identifies two dimensions for skill, namely, skill level and skill specialization. Skill level is defined as “the complexity and range of tasks and duties to be performed in an occupation” (International Labour Office 2012). Skill specialization identifies “the field of knowledge required, the tools and machinery used, the materials worked on or

[22] In German: Klassifikation der Berufe (KldB)

[23] This sub-chapter 4.2.1 is mainly written based on (International Labour Office 2012)

with, and the kinds of goods and services produced" for a job (International Labour Office 2012).

ISCO is structured in a four-level hierarchy, in which occupations are grouped based on the similarities in skill level and skill specification. The top level of ISCO-08 is divided into 10 major groups, the second level called sub-major group consists of 43 categories, the third level called minor group has 130 categories and finally, the bottom level called unit group which can be considered as a job, has 436 categories.

Referring to the aforementioned groups, ISCO identifies a digit code to specify each job: major group denoted by first-left-digit (e.g. X_1 =2-Professional), sub-major group denoted by second-left-digit (e.g. X_2 =2-Health Professionals), minor group denoted by third-left-digit (e.g. X_3 =2-Nursing and Midwifery Professional), and unit group denoted by fourth-left-digit (e.g. X_4 =1 Nursing Professionals). Figure 21 visualizes the abovementioned description of the ISCO four-digit.

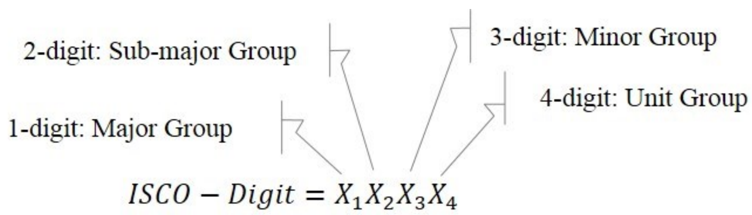

Figure 21 How ISCO-Digit is Built Up - Adopted from (International Labour Office 2012)

The skill level required to perform a job is identified for the major groups and consequently the sub-groups. Correspondingly, the bottom groups inherit the identified skill level(s) from their major group. The ISCO skills are distinguished into four levels:

1st skill level: simple and routine physical or manual tasks (e.g. 9412-Kitchen Helpers), which need the first stage of the basic education.

2nd skill level: the ability to read information, perform operating machinery, electronic equipment, and so on. For this level, the jobholder needs to complete at least the first stage of secondary education. Moreover, vocation-specific education can be requested, depending on the type of the job (e.g. 5321-Health Care Assistants).

3rd skill level: complex technical and practical tasks that support the jobholders in obtaining factual, technical, and procedural knowledge in their field (e.g. 33221-Nursing Associate Professional).

4th skill level: these tasks are based on complex problem-solving, decision-making, and creativity. Thus, the job holder should possess the highest level of the communication skills, and should demonstrate a first degree or higher qualification (e.g. 2221-Nursing Professionals).

The ISCO skill level is mapped to ISCED-97[24] (cf. Chapter 5.2), due to the identification of the formal education and training requirement. Figure 22 shows the relationship between major groups and the four-skill level. Moreover, the legend of this figure illustrates the relation between skill levels and ISCED-97.

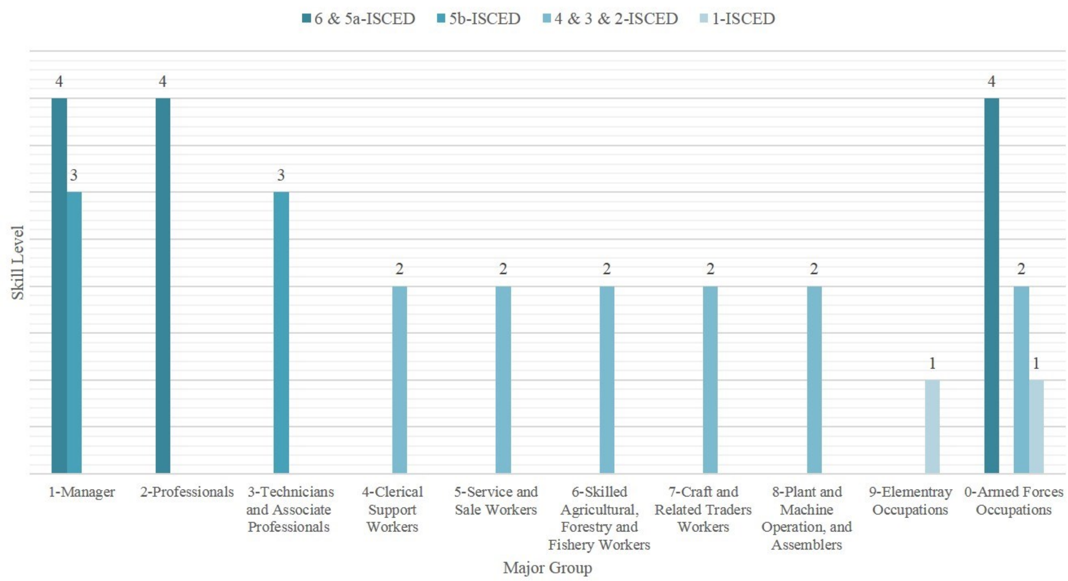

Figure 22 Skill and Education Level Required for the Major Groups - Adopted from (International Labour Office 2012) and (UNESCO Institute for Statistics 2014)

4.2.2 German Standard of Classification of Occupation (KldB)

Since in the present work the national focus is placed on Germany, the German standard of classification of occupation 2010 (KldB), which is the latest version published by the German Federal Employment Agency, is studied[25]. KldB defines two dimensions for occupation classification, the horizontal and vertical dimensions. Horizontal dimension determines expertise of an occupation, while vertical dimension identifies the degree of complexity within the occupations. The expertise of an occupation is defined by the level of skill, knowledge, and ability required to perform the occupation.

KldB is hierarchically structured in five levels. As Figure 23 presents, the first fourth digits specify the occupational expertise of a job and elaborate on the job by going through the next

[24] Refers to International Standard Classification of Education

[25] This such-chapter 4.2.2 is mainly written based on (Bundesagentur für Arbeit 2011)

digits from left to right (X_1- X_4). The fifth digit (X_5), bottom level, can identify as follows (Paulus and Matthes 2013):

(1) Unskilled or semi-skilled activities, which require no vocational qualification, or regular one-year vocational training.

(2) Specialist activities, which require at least two years of vocational training.

(3) Complex specialist activities, which require "qualification as a master craftsman or technician or equivalent technical school or college graduation, also graduation from a professional academy or university bachelor's degree".

(4) Highly complex activities, which require university studies of at least four years (minimum Bachelor).

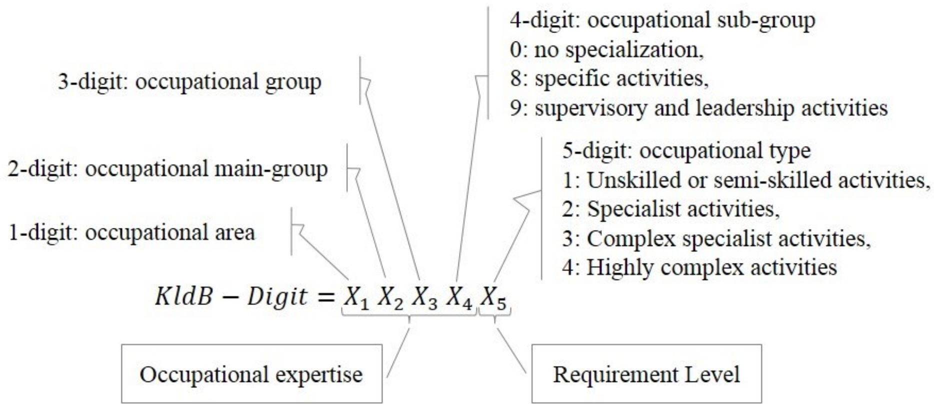

Figure 23 Structure of KldB digit - Adopted from (Bundesagentur für Arbeit 2011)

4.2.3 Conversion from KldB 2010 to ISCO-08

Mapping the jobs of the national level to the international level facilitates the communication with the jobs of the other countries, which map their occupations to the international standard. In this way, ISCO can be taken into account as a mediator, which connects the jobs across the countries. The benefit is finding out, for instance, which job in France or Spain is the same as, or comparable to, the nursing job in Germany.

The main aim of the development of the new version of KldB (Kldb-2010) was compatibility with ISCO-08. Therefore, it is obvious that approximately 90 percent of the jobs specified in the lowest level of KldB 2010 (labeled as "Berufsgattungen") can be mapped to one of the jobs of the lowest level of ISCO-08 (labeled as "unit group"). The conversion table from KldB 2010 to ISCO-08 appears in Appendix 1 of (Bundesagentur für Arbeit 2011).

4.3 Conceptualization of WoW Domain

The WoW domain consists of the two dimensions of i) Task and ii) Job-KSC. In the following, the concepts of WoW domain of Job-Know Ontology are elaborated. In the first stage, to have a common understanding of the terms, the glossary of the WoW domain, which includes six terms, is established. Table 7 identifies the ID of the term, definition and the source, from which the definition is taken.

Table 7 Job-Know Glossary - Part of WoW

ID	*Term*	*Definition*	*Source*
G1	*Occupation*	*A set of jobs, whose main tasks and duties are characterized by a high degree of similarity*	(International Labour Office 2012)
G2	*Job*	*A set of tasks and duties defined by the employer(s) and performed, or meant to be performed, by employee(s), for an employer or in self-employment. The job is defined by job description including tasks, specified and elaborated by job specification, including KSCs.*	(International Labour Office 2012)
G3	*Task*	*A quite detailed way of describing a job, and identifies by an action verb, the object of the action, the source of information or instruction, and the results in the job description* *A task is described by the job description as a statement, which should reply to three main categories of questions i) Do what? ii) To what? and iii) For what purpose?/With what?/ To whom?/What type?. The type of answers to the above-mentioned questions are i) the action (i.e. the verb), ii) the noun and iii) the noun, respectively. The verb can be categorized into the linear process (e.g. build) or a cyclic process (e.g. develop).*	(Morgeson and Campion 2011), (Smit-Voskuijl 2005), (Moore 1999)
G4	*Knowledge*	*"Outcome of assimilation of information through learning. Knowledge is the body of facts, principles, theories, and practices related to a field of study or work".*	(European Parliament 2008)
G5	*Skill*	*"Ability to apply knowledge and use know-how to complete tasks and solve problems".*	(European Parliament 2008)
G6	*Competence*	*"Ability to use knowledge, skills, and personal, social, and/or methodological abilities, in work or study situations and in professional and personal development".*	(European Parliament 2008)

4.3.1 Conceptualization of Job and Task

To conceptualize a job, two international and national standards are taken into account. The hierarchical structures of both standards are used as the basis of the model (cf. Figure 24); therefore, four concepts of *Major Group, Sub-major Group, Minor-Group,* and *Unit Group* are defined to approach a job with the international perspective. On the flipside, to nationalize the job, five concepts are defined, which follows the hierarchical structure of KldB, namely, *Occupational Area*[26], *Occupational Main-group*[27], *Occupational Group*[28], *Occupational Sub-group*[29] and *Occupational Type*[30].

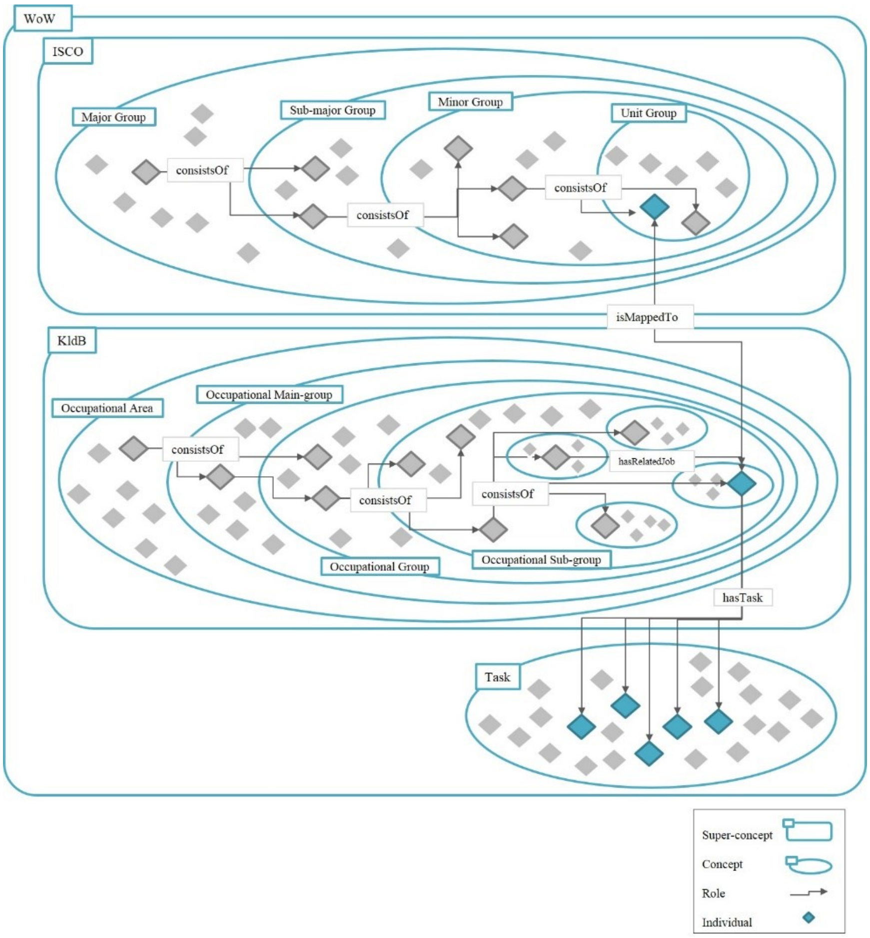

Figure 24 The Super- and Sub-Concepts to Define Job and Task

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[26] In German: Berufsbereiche

[27] In German: Berufshauptgruppen

[28] In German: Berufsgruppen

[29] In German: Berufsuntergruppen

[30] In German: Berufsgattungen

All jobs are identical in Job-Know Ontology based on the definition taken from ISCO and KldB (approx. in 90 per cent). Figure 28 depicts the part of the super-concepts and sub-concepts of the WoW domain of Job-Know Ontology described above to identify a job with ISCO-digit and KldB-digit.

There is a (part-whole) role entitled *consistsOf()*, which relates the super-concepts of ISCO and KldB to their own sub-concepts. To map the job defined by ISCO and the job defined by KldB a symmetric role of *isMappedTo()* is specified. This role is applied at the lowest level of both concepts. Finally, to relate the jobs, which have similarities, the role of *hasRelatedJob()* is defined.

A job includes tasks, which are described by means of the job description and the required KSCs specified by the job specification. The concept of *Task* in WoW domain consists of all the tasks identified by KldB. The role of *hasTask()* relates the job to its tasks. Notably, a task(s) can be related to more than one job. The bottom part of Figure 24 visualizes the role between *Task* and *Job* concepts.

Moreover, a job has task dependencies (*TD*) to its tasks, which shows how much the job is dependent on the task. Each task of the job is just identified by a unique *TD*. The *TD* is distinguished into four degrees as detailed by Table 8.

Table 8 Task Dependency in Detail

TD	***Description***	***Value***
Strong dependency	*Job j_x is strongly dependent on the Task t_i*	*3*
Moderate dependency	*Job j_x is moderately dependent on Task t_i*	*2*
Weak dependency	*Job j_x is weakly dependent on Task t_i*	*1*
No dependency	*Job j_x is not dependent on Task t_i*	*0*

A task has characteristics which determine the frequency, shift, autonomy, interdependency, specificity, criticality, and difficulty. Table 9 presents the task characteristics and their scales in detail.

Table 9 Task Characteristics, Scales and Descriptions

Task characteristic	***Scale***	***Description***
Task frequency	*Very Often*	*Task t_i is very often performed in Job j_x*
	Sometimes	*Task t_i is sometimes performed in Job j_x*
	Rarely	*Task t_i is rarely performed in Job j_x*

Task characteristic	***Scale***	***Description***
	Never	*Task t_i is never performed in Job j_x*
Shift	*Day shift*	*Task t_i is performed for Job j_x from approximately 8:00 a.m. to 5:00 p.m.*
	Night shift	*Task t_i is performed for Job j_x from approximately 5:00 p.m. to 8:00 a.m.*
Autonomy	*To a Great Extent*	*Task t_i has to a great extent autonomy in Job j_x*
	Somewhat	*Task t_i has somewhat autonomy in Job j_x*
	Very Little	*Task t_i has very little autonomy in Job j_x*
	Not at All	*Task t_i has not any autonomy in Job j_x*
interdependency	*Pooled*	*Task t_i of Job j_x is not directly interacted and do not directly depend on the other jobs*
	Sequential	*The output of Task t_i of Job j_x is necessary for performance of the other jobs*
	Reciprocal	*The output of the tasks of the other job(s) is the input of Task t_i of Job j_x, and it goes cyclically*
Specificity	*General*	*The task t_i is a typical task for such a job j_x*
	Specific	*The task t_i is a specific task for job j_x*
Criticality	*To a Great Extent*	*Task t_i has to a great extent critical task in Job j_x*
	Somewhat	*Task t_i has somewhat critical task in Job j_x*
	Very Little	*Task t_i has very little critical task in Job j_x*
	Not at All	*Task t_i has not any critical task in Job j_x*
Difficulty	*Expert*	*To perform Task t_i of Job j_x, at least the expert level of experience is required*
	Advanced	*To perform Task t_i of Job j_x, at least the advance level of experience is required*
	Intermediate	*To perform Task t_i of Job j_x, at least the intermediate level of experience is required*
	Novice	*To perform Task t_i of Job j_x, at least the novice level of experience is required*
	Beginner	*To perform Task t_i of Job j_x, at least the beginner level of experience is required*

The aforementioned characteristics of tasks can be defined by two views: i) the employer/job designer, and ii) the employee. In both cases, the entry data is subjective (organization-specific) and may differ from one organization to another.

4.3.2 Conceptualization of Job-KSC

To perform the tasks of a job, a level of Job-KSCs are required. Considering the earlier discussion in Chapter 2 and 3, it is obvious that Job-KSCs enable employees to perform the assigned tasks. In order to group the KSCs the concept of *Job-KSC* is defined. The *Task* concept responses to the question of "What should be done?" and *Job-KSC* concept provides the answer to the question of "What know-what, know-how, know-why are required to be able to perform the task?"

The task characteristics, defined above, justify that the KSC degrees required performing the tasks of the job are not the same. Thus, a demand degree (*DD*) is defined which identifies the dependency of a task to a Job-KSC. *DD* is distinguished to four degrees detailed in Table 10.

Table 10 Demand Degree (DD) in detail

DD	***Description***	***Value***
Strong dependency	*Task t_i requires strongly Job-KSC c_j*	*3*
Moderate dependency	*Task t_i requires moderately Job-KSC c_j*	*2*
Weak dependency	*Task t_i requires weakly Job-KSC c_j*	*1*
No dependency	*Task t_i requires No Job-KSCs c_j*	*0*

According to the definition of European Parliament and EQF (cf. Chapter 5), there are three categories of requirements to perform a job, namely knowledge, skill, and competence. These categories are used here to differentiate **know-what** as ***Knowledge*** **concept** (i.e. clear recognition of the objective of a selected course of action), **know-how** as ***Skill*** **concept** (i.e. knowledge of how to do something smoothly and efficiently), and **know-why** as ***Competence*** **concept** (i.e. understanding of the reasons underlying something as a course of action). Furthermore, these concepts are employed to identify which KSC are required to perform a job, independent of each other. In this way, for instance, it becomes evident, what basic knowledge is needed to perform a specific task.

The role of *requires()* relates the *Task* concept to the *Job-KSC* concept. This super-role consists of the sub-roles which are specified by the *DD* of a task, and, a Job-KSC based on the description given in Table 10. The bottom part of Figure 25, which is marked in blue, presents the concepts of *Task*, *Job-KSC* and their relation.

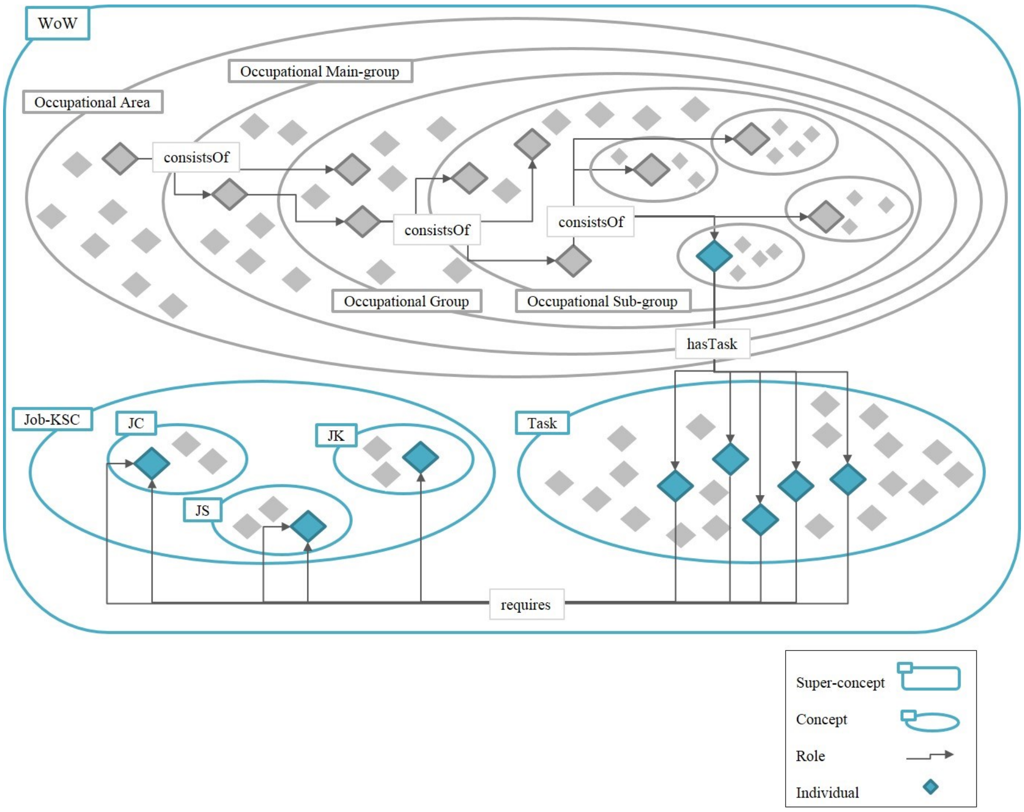

Figure 25 Task and Job-KSC Concepts and Roles

4.4 Formalization of T-Box of WoW Domain

There are two types of concept and role needed to formalize the ontology, namely, atomic and complex (cf. Chapter 2.3.1). The first is the basis to formalize the latter. The atomic concepts and roles are marked with (A), while the complex ones are marked with (C). In the following, firstly the concepts, which are defined and conceptualized by the previous sub-chapter, are formalized, and later the roles.

4.4.1 Concepts of WoW Domain

To formalize the concepts of WoW domain the atomic concepts are introduced and, based on them, the complex concepts are elaborated.

- The *task* is an atomic concept describing what should be performed (cf. Table 7 – G3).

$$Task(t) \supset reuires.Job - KSC(jksc)$$

(WoW-D1-A)

- *Task* concept includes the *Task Characteristics* concept which includes the sub-concept defined by Table 9.

$$TaskCharacteristics(tc) \supset \exists_{=1} f\ hasFrequency.Frequency(f) \vee \exists_{\geq 1} s\ hasShift.Shift(s) \vee \exists_{=1} a\ hasAutonomy.Autonomy(a) \vee \exists_{=1} i\ hasInterdependency.Interdependency(i) \vee \exists_{=1} p\ hasSpecificity.Specificity(p) \vee \exists_{=1} r\ hasCriticality.Criticality(r) \vee \exists_{=1} u\ hasDifficulty.Difficulty(u)$$

(WoW-D2-A)

- The sub-concepts of Task Characteristics are contained of following individuals.

$$Frequency(f) = \{Very\ Often, Sometimes, Rarely, Never\}$$
$$Shift(s) = \{Day\ shift, Night\ shift\}$$
$$Autonomy(a) = \{To\ a\ Great\ Extent, Somewhat, Very\ Little, Not\ at\ All\}$$
$$Interdependency(i) = \{Pooled, Sequential, Reciprocal\}$$
$$Specificity(p) = \{General, Specific\}$$
$$Criticality(r) = \{To\ a\ Great\ Extent, Somewhat, Very\ Little, Not\ at\ All\}$$
$$Difficulty(u) = \{Expert, Advanced, Intermediate, Novice, Beginner\}$$

- The *Job* is a set of tasks, which has a specific *ISCO-digit* and *KldB-digit* (cf. Table 7 – G2).

$$Job(j) \equiv hasDigit.KldBDigit(k) \wedge hasDigit.(isMappedTo.KldBDigit(k))$$
$$Job(j) \supset hasTask.Task(t)$$

(WoW-D3-C)

- The *KldB-digit* concept consists of Occupational Area, Occupational Main-group, Occupational Group, Occupational Sub-Group, and Occupational Type sub-concepts. Notably, each of the sub-concepts contains specific individuals.

$$KldBDigit(kd) \equiv \exists_{=1} hasOccupationalArea.OccupationalArea(oa) \wedge \exists_{=1} hasOccupationalMainGroup.OccupationalMainGroup(om) \wedge \exists_{=1} hasOccupationalGroup.OccupationalGroup(og) \wedge \exists_{=1} hasOccupationalSubGroup.OccupationalSubGroup(os) \wedge \exists_{=1}\ hasOccupationalType.OccupationalType(ot)$$

(WoW-D4-C)

- *ISCO-digit* is structured in a four-level hierarchical, which is detailed from Major Group to Sub-Major Group, then Sub-Major Group to Minor Group and at the bottom level, Minor Group to Unit Group sub-concepts. Notably, each of the sub-concepts contains specific individuals.

$$\exists ISCODigit(id) \equiv \exists_{=1} hasMajor.MajorGroup(mg) \wedge \exists_{=1} hasSubMajorGroup.SubMajorGroup(sg) \wedge \exists_{=1} hasMinorGroup.MinorGroup(ig) \wedge \exists_{=1} hasUnitGroup.UnitGroup(ug)$$

$$ISCODigit(id) \supset isMappedTo.KldBDigit(k\ )$$

(WoW-D5-C)

- *Job-KSC* consists of entire Knowledge, Skill, and Competence required to perform the tasks of the job.

$$Job - KSC(jksc) \equiv consistsOf.(JobKnowledge(jk) \vee JobSkill(js) \vee JobCompetence(jc))$$

(WoW-D6-C)

- *Job Knowledge* is an atomic concept which groups the body of facts, principles, theories, and practices related to the field of study or work required to perform a job (cf. Table 7 – G4).

$$JobKnowledge(jk) \supset enables.Task(t)$$

(WoW-D7-A)

- *Job Skill* is an atomic concept which groups the ability to apply knowledge and use know-how to complete tasks and solve problems (cf. Table 7 – G5).

$$JobSkill(js) \supset enables.Task(t)$$

(WoW-D8-A)

- *Job Competence* is an atomic concept which groups ability to use knowledge, skills and personal, social, and/or methodological abilities, in work or study situations and in professional and personal development (cf. Table 7 – G6).

$$JobCompetence(jc) \supset enables.Task(t)$$

(WoW-D9-A)

4.4.2 Roles of WoW Domain

In fact, to identify the semantic between the concepts, the roles need to be defined. The roles of the WoW domain of the Job-Know Ontology are formalized based on the definition given in the Conceptualization phase. Similarly, in the following the atomic roles are marked with (A) and complex ones with (C).

- A job identifies with two kinds of digits: the KldB-digit (WoW-D4) and the ISCO-digit (WoW-D5). Here, the role of *hasDigit()* is defined to relate the job to its digits.

(WoW-R1-A)

- The role of *consistsOf()* is defined to relate the whole to the part (super-concepts to the sub-concepts). Its inverse role is *isPartOf()*.

(WoW-R2-A)

- The job, which is identified in the bottom level of KldB in the *Occupational Type* concept, is related to the job of the ISCO in the *Unit Group* via the symmetric role of *isMapped tTo()*.

(WoW-R3-A)

- A job is related to the Task concept and is contained in a task via the role of *hasTask()*. Its inverse role is *isTaskOf()*. Each task has a *TD* to the job, therefore, the super-role of *has-Task()* is detailed to sub-roles of *hasTask-Not()* for *TD*=0, *hasTask-Weakly()*for *TD*=1, *hasTask-Moderately()* for *TD*=2, *hasTask-Strongly()* for *TD*=3. The default role is *hasTask-Not()*, which means there is no relation between the task and the job.

$$hasTask-Strongly(j,t) \vee hasTask-Moderately(j,t) \vee hasTask-Weakly(j,t) \vee hasTask-Not(j,t) \supset hasTask(j,t)$$

(WoW-R4-C)

- The relation between *Task* and *Job-KSC* concepts are defined as super-role of *requires()*, where the *DD* elaborates the sub-roles of *requires-Not()* for *DD*=0, *requires-Weakly()* for *DD*=1, *requires-Moderately()* for *DD*=2, *requires-Strongly()* for *DD*=3. The inverse role of *requires()* is *enables()*. The default role is *requires-Not()*, which means there is no relation between the task and the Job-KSC.

$$requires-Strongly(t,ksc) \vee requires-Moderately(t,ksc) \vee requires-Weakly(t,ksc) \vee requires-Not(t,ksc) \supset requires(t,ksc)$$

(WoW-R5-C)

4.5 Instantiation of WoW Domain

After conceptualization and formalization of the T-Box (i.e. concepts and roles), the concepts should be instantiated and populated with respect to a specific job and its tasks. After visualization of an A-Box, the following the matrices (WoW-M1 – WoW-M7) are introduced to identify the individuals of WoW. In this phase, the KP (e.g. domain expert) and KA are responsible to identify the individuals based on the matrices.

4.5.1 Visualization of an A-Box

Figure 26 exemplifies an A-Box, which visualizes the relationship between the individuals of the *Job*, *Task* and *Job-KSC* concepts. The data is taken from WoW-M1.1 and WoW-M2.1. The blue oval represents the concepts, the diamonds represent the individuals, and the lines illustrated the roles.

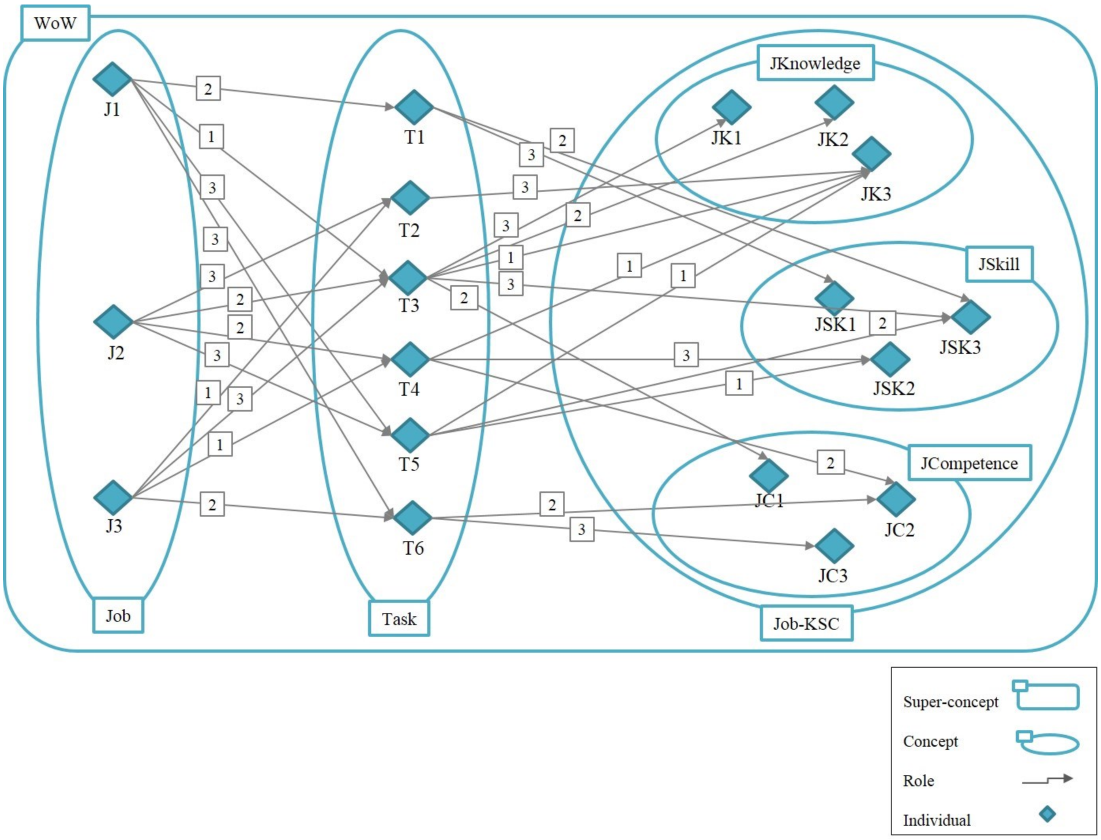

Figure 26 Part of the T-Box and A-Box of Job-Know Ontology

Three jobs, six tasks, and nine Job-KSC are identified in Figure 26 as an example. The relation between Job and Task is super-role of *hasTask()*, where the value on the role (cf. Figure 26) shows the *TD* of the selected job and the selected task (e.g. J1 *hasTask-Moderately* to T3, however, J2 *hasTask-Strongly* to T3). Moreover, the super-role of *requires()* makes a role between Task and required Job-KSC (e.g. T3 *requires-Strongly* to JSK3, however, T5 T3 *requires-Moderately* to JSK3).

4.5.2 Job-Task Matrix

Job-Task (JT) matrix is established to instantiate the individual tasks of the *Task* concept and relate the individual jobs of the *Job* concept to the tasks via the sub-role of *hasTask()* (WoW-R4). The cells, therefore, are valued based on Table 8 which are $TD \in \{0, 1, 2, 3\}$ and refer to *hasTask-Not()*, *hasTask-Weakly()*, *hasTask-Moderately()*, *hasTask-Strongly(),* respectively.WoW-M1 represents the jobs of the WoW (i.e. the rows), the tasks of WoW (i.e. the columns), and the *TD* via the sub-role of *hasTask()* (i.e. in cells). The default value is *hasTask-Not(),* which is equal with (0).

$$JT_{a\times b} = \begin{bmatrix} hasTask(job_1, task_1) & \cdots & hasTask(job_1, task_b) \\ \vdots & \ddots & \vdots \\ hasTask(job_a, task_1) & \cdots & hasTask(job_a, task_b) \end{bmatrix}_{a\times b}$$

(WoW-M1)

The $JT_{a\times b}$ matrix is firstly filled out based on the sub-roles defined by WoW-R4-C which then refers to the type of role, before it is transferred to the numerical matrix. For an example, the role of *hasTask-Weakly*(j_1,t_5) is filled in the cell of the first row and fifth column by (1). WoW-M1.1 exemplifies the $JT_{3\times 6}$ matrix.

$$JT_{3\times 6} = \begin{bmatrix} 2 & 0 & 1 & 0 & 3 & 3 \\ 0 & 3 & 2 & 2 & 3 & 0 \\ 0 & 1 & 3 & 1 & 0 & 2 \end{bmatrix}_{3\times 6}$$

(WoW-M1.1)

4.5.3 Task-Competence Matrix

Task-Competence (TC) matrix is established, where the columns show the tasks described to perform the job and the rows show the Job-KSC required to perform the described tasks. The cells, therefore, are valued based on Table 10, which defined as $DD \in \{0, 1, 2, 3\}$. These values are a numerical form of the sub-roles of *requires()* (WoW-R5). WoW-M1 represents the tasks of the job (i.e. the rows), the Job-KSC (i.e. the columns) and the *DD* via the sub-roles of *requires()* (i.e. in cells).

$$TC_{i\times j} = \begin{bmatrix} requires(task_1, ksc_1) & \cdots & requires(task_1, ksc_j) \\ \vdots & \ddots & \vdots \\ requires(task_i, ksc_1) & \cdots & requires(task_i, ksc_j) \end{bmatrix}_{i\times j}$$

(WoW-M2)

The $TC_{i\times j}$ matrix is firstly filled out based on the sub-roles defined by WoW-R5-C, and then when it refers to the type of the role, it is transferred to the numerical matrix. For example, the role of task t_3 and KSC ksc_6, which is *requires-Strongly*(t_3,ksc_6), is identified by (3) in a cell of the third row and sixth column of the matrix. WoW-M2.1 exemplifies the $TC_{6\times 9}$ matrix.

$$TC_{6\times 9} = \begin{bmatrix} 0 & 0 & 0 & 3 & 0 & 2 & 0 & 0 & 0 \\ 0 & 0 & 3 & 0 & 0 & 0 & 0 & 0 & 0 \\ 3 & 2 & 1 & 0 & 0 & 3 & 2 & 0 & 0 \\ 0 & 0 & 1 & 0 & 3 & 0 & 0 & 2 & 0 \\ 0 & 0 & 1 & 0 & 1 & 2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 3 \end{bmatrix}_{6\times 9}$$

(WoW-M2.1)

4.5.4 Sum of KSC-Job Matrix

If cells of the *TC* matrix (WoW-M1), which are not filled out with 0, are considered as 1 otherwise 0, the sum of the rows of each column identifies how much a specific Job-KSC is required to perform the job. In this way, the *SumC* matrix is a matrix with *j* columns (i.e. the number of Job-KSC required to perform the job). The matrix is defined as WoW-M3:

$$SumC_{1\times j} = \begin{bmatrix} \sum_{i=1}^{i=Number\ of\ Tasks} t_i c_1 & \dots & \sum_{i=1}^{i=Number\ of\ Tasks} t_i c_j \end{bmatrix}$$

(WoW-M3)

WoW-M3.1 exemplifies the *SumC* matrix based the values given by WoW-M1.1.

$$SumC_{1\times j} = [1 \quad 1 \quad 4 \quad 1 \quad 2 \quad 3 \quad 1 \quad 2 \quad 1]$$

(WoW-M3.1)

4.5.5 Sum of KSC-Task Matrix

In another way, if cells of the *TC* matrix (WoW-M1), which are not filled out with 0, are considered as 1 otherwise 0, the sum of the columns of a row identifies how much a task requires Job-KSCs in total to be performed. The *SumT* matrix is a matrix with *i* rows (i.e. the number of the tasks that should be performed for the job) and one column. The matrix is defined as WoW-M4.

$$SumT_{i\times 1} = \begin{bmatrix} \sum_{j=1}^{j=Number\ of\ Job-KSCs} t_1 c_j \\ \vdots \\ \sum_{j=1}^{j=Number\ of\ Job-KSCs} t_i c_j \end{bmatrix}$$

(WoW-M4)

WoW-M4.1 exemplifies the *SumC* matrix based the values given by WoW-M1.1.

$$SumT_{i\times 1} = \begin{bmatrix} 1 \\ 1 \\ 5 \\ 3 \\ 3 \\ 2 \end{bmatrix}$$

(WoW-M4.1)

4.5.6 Strongest KSC-Job Matrix

The *MaxKSCenablesJ* matrix is a 2-dimensional (2-D) matrix, which is established based on the *TC* matrix to represent:

- 1-D: the maximum value of the rows of a column of $TC_{i\times j}$ matrix that identify which Job-KSC is required more than the other Job-KSCs to perform the job. To extract this data, the function of $\max_{i\in number\ of\ Tasks} DD_{i\times j}$ is applied on the columns of $TC_{i\times j}$ matrix.
- 2-D: the index of the row (task) of $TC_{i\times j}$ matrix, which requires the Job-KSC with the maximum value (1-D) via applying the function of $\operatorname{argmax}_{i\in number\ of\ Tasks} DD_{i\times j}$.

The number of rows (e) of the *MaxKSCenablesJ* shows there is more than one task which has the maximum value. The WoW-M3 represents the $MaxKSCenablesJ_{e\times j}$ matrix.

$$MaxKSCenablesJ_{e\times j} = \left[\left(\max_{i\in number\ of\ Tasks} DD_{i\times 1}, \operatorname{argmax}_{i\in number\ of\ Tasks} DD_{i\times 1}\right) \ \dots \ \max_{i\in number\ of\ Tasks} DD_{i\times j}, \operatorname{argmax}_{i\in number\ of\ Tasks} DD_{i\times j}\right]$$

(WoW-M5)

WoW-M5.1 exemplifies the *MaxKSCenablesJ* matrix based on the values given by WoW-M1.1.

$$MaxKSCenablesJ_{2\times 9} = \begin{bmatrix} (3,3) & (2,3) & (3,2) & (3,4) & (1,4) & (3,3) & (2,3) & (2,4) & (3,6) \\ - & - & - & - & - & - & - & (2,6) & - \end{bmatrix}$$

(WoW-M5.1)

4.5.7 Strongest KSC-Task Matrix

The *MaxKSCenablesT* matrix is a 2-dimensional (2-D) matrix, which is established based on the $TC_{i\times j}$ matrix matrix to represent:

- 1-D: the maximum value of the columns of a row of $TC_{i\times j}$ matrix that identify which specific Job-KSC is required more than the other Job-KSCs to perform the specific task. To extract data, the function of $\max_{j \in number\ of\ KSCs} DD_{i\times j}$ is applied on the rows of the $TC_{i\times j}$ matrix.
- 2-D: the index of the column (KSC) of $TC_{i\times j}$ matrix, which enables the task with the maximum value (1-D) via applying the function of $\operatorname{argmax}_{j \in number\ of\ KSCs} DD_{i\times j}$.

The number of the column (l) of the *MaxKSCenablesT* shows there is more than one Job-KSC, which has the maximum value. The WoW-M4 represents the $MaxKSCenablesT_{i\times l}$ matrix.

$$MaxKSCrenablesT_{i\times l} = \begin{bmatrix} (\max_{j \in number\ of\ KSCs} DD_{1\times j}, & \operatorname{argmax}_{j \in number\ of\ KSCs} DD_{1\times j}) \\ & \vdots \\ (\max_{j \in number\ of\ KSCs} DD_{i\times j}, & \operatorname{argmax}_{j \in number\ of\ KSCs} DD_{i\times j}) \end{bmatrix}$$

(WoW-M6)

WoW-M6.1 exemplifies the *MaxKSCenablesT* matrix based on the values given by WoW-M1.1.

$$MaxKSCrenablesT_{6\times 2} = \begin{bmatrix} (3,4) & - \\ (3,3) & - \\ (3,1) & (3,6) \\ (3,5) & - \\ (2,6) & - \\ (3,9) & - \end{bmatrix}$$

(WoW-M6.1)

4.5.8 Job-KSC Matrix

The Job-KSC matrix is to identify the Job-KSCs required to perform the main tasks of the job. The main tasks are those tasks related to the job via the sub-role of *hasTask-Strongly().* According to the values given by WoW-M1, the sort of task, which is related to the job via *hasTask-Strongly()*, are selected and the index of the task fills the cells of *SpecificJT* matrix (WoW-M7). Then the KSCs required to perform these tasks are extracted from the WoW-M2 and placed in *SpecificTC* matrix (WoW-M8).

$$SpecificJT = [hasTask - Strongly(job_1, task_x) \quad \ldots \quad hasTask - Strongly(job_1, task_y)]_{1 \times number\ of\ hasTask-Strongly\ relation}$$

(WoW-M7)

$$SpecificTC \begin{bmatrix} requires(task_x, ksc_1) & \cdots & requires(task_v, ksc_j) \\ \vdots & \ddots & \vdots \\ requires(task_y, ksc_1) & \cdots & requires(task_y, ksc_j) \end{bmatrix}_{number\ of\ selected\ tasks \times j}$$

(WoW-M8)

WoW-M7.1 and WoW-M8.1 exemplify the *SpecificJT* and *SpecificTC* matrices, respectively, based on the values given WoW-M1.1 and WoE-M2.1.

$$SpecificJT_{1\times2} \quad [5 \quad 6]_{1\times2}$$

(WoW-M7.1)

$$SpecificTC_{2\times9} \quad \begin{bmatrix} 0 & 0 & 1 & 0 & 1 & 2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 3 \end{bmatrix}_{6\times9}$$

(WoW-M8.1)

4.6 Inferences of WoW Cases

With respect to the aforementioned T-Box and A-Box defined for the WoW domain, the following cases are inferred to provide the answer of the fist category of CQs (cf. Chapter 3.3). The condition, description, and formalization of cases are detailed as follows.

***Case 1**: Unique Job-K S C*

- **Description**: Just t_a requires uniquely ksc_b. It means ksc_b is a unique Job-KSC to perform this job and none of the tasks of this job requires ksc_b. This result is inferred from the *SumC* matrix (WoW-M3), which presents the number of the Job-KSCs required for the job.

$$\exists_{=1} t_a, ksc_b \ \forall t \ Task(t_a) \wedge JobKSC(ksc_b) \wedge requires(t_a, ksc_b) \bigwedge_{i \in number\ of\ Tasks, i \neq a} requires - Not(t_i, ksc_b) \supset UniqueJobKSC(ksc_b)$$

(WoW-I1)

For instance, according to WoW-M3.1, the three Job-KSCs of ksc_1, ksc_2, ksc_7 are the unique KSCs for this job. Figure 27 illustrates the results.

TC Matrix	KSC 1	KSC 2	KSC 3	KSC 4	KSC 5	KSC 6	KSC 7	KSC 8	KSC 9
Task 1	0	0	0	3	0	2	0	0	0
Task 2	0	0	3	0	0	0	0	0	0
Task 3	3	2	1	0	0	3	2	0	0
Task 4	0	0	1	0	3	0	0	2	0
Task 5	0	0	1	0	1	2	0	0	0
Task 6	0	0	0	0	0	0	0	2	3
Trend									
SumC	**1**	**1**	**4**	**1**	**2**	**3**	**1**	**2**	**1**
	Case 1	**Case 1**		**Case 1**			**Case 1**		**Case 1**

Figure 27 Case1- an example: the rows show the tasks, the column KSCs, and the cells DD

***Case 2**: Unique Task Enabler*

- **Description:** Just ksc_b enables uniquely t_a. This means to perform t_a just one Job-KSC is required, which is ksc_b. However, it is possible that the other tasks of this job require this Job-KSC as well. This result is inferred from the *SumT* matrix (WoW-M4), which presents the number of the KSC required for the specific task.

$$\exists_{=1} t_a, ksc_b\ \forall ksc\ Task(t_a) \wedge JobKSC(ksc_b) \wedge requires(t_a, ksc_b) \bigwedge_{j \in number\ of\ KSCs, j \neq b} requires-Not(t_a, ksc_j) \supset UniqueTask(t_a)$$

(WoW-I2)

For example, according to WoW-M4.1, Task t_2, requires a unique KSC ksc_3. Figure 28 illustrates the results.

TC Matrix	KSC 1	KSC 2	KSC 3	KSC 4	KSC 5	KSC 6	KSC 7	KSC 8	KSC 9	Trend	SumT	
Task 1	0	0	0	3	0	2	0	0	0		**2**	
Task 2	0	0	3	0	0	0	0	0	0		**1**	**Case 2**
Task 3	3	2	1	0	0	3	2	0	0		**5**	
Task 4	0	0	1	0	3	0	0	2	0		**3**	
Task 5	0	0	1	0	1	2	0	0	0		**3**	
Task 6	0	0	0	0	0	0	0	2	3		**2**	

Figure 28 Case2-an example: SumT to extract the unique KSC

***Case 3**: Strongest Job Enabler*

- **Description:** ksc_b has the strongest effect on performing the job, where there is *requires-Strongly()* role between t_i and ksc_b. The result is inferred from *MaxKSCenablesJ* Matrix (WoW-M5).

$$\exists t_a, ksc_b\ \forall t\ Task(t_i) \wedge JobKSC(ksc_b) \bigwedge_{i \in number\ of\ Tasks} requires - Strongly(t_i, ksc_b) \supset StrongestJobEnabler(ksc_b)$$

(WoW-I3)

As an example, according to WoW-M5.1, KSC ksc_1, ksc_3, ksc_4, ksc_6, ksc_9 are the strongest KSCs, which enable (employees) to perform this job. Figure 29 illustrates the results.

MaxKSCenablesJ Matrix	TREND	KSC 1	KSC 2	KSC 3	KSC 4	KSC 5	KSC 6	KSC 7	KSC 8	KSC 9
Strongest value of KSC-J1		3	2	3	3	1	3	2	2	3
		Case 3		Case 3	Case 3		Case 3			Case 3

Figure 29 Case 3- an example: MaxKSCenablesJ matrix to extract the strongest job enabler

***Case 4**: Strongest Task Enabler*

- **Description:** ksc_b has the strongest effects on performing the task. The result is inferred from *MaxKSCenablesT* Matrix (WoW-M6).

$$\exists t_a, ksc_b\ \forall ksc\ Task(t_a) \wedge JobKSC(ksc_b) \bigwedge_{j \in number\ of\ KSCs} requires - Strongly(t_a, ksc_j) \supset StrongestTaskEnabler(ksc_b)$$

(WoW-I4)

For instance, according to WoW-M6.1, KSC ksc_1 for Task t_3, KSC ksc_3 for Task t_3, KSC ksc_4 for Task t_1, KSC ksc_5 for Task t_4, KSC ksc_9 for Task t_6 are the strongest KSCs, which enable (employees) to perform the aforementioned tasks. Figure 30 illustrates the results.

MaxKSCenablesT Matrix	Strongest value of KSC-T	KSC which has the strongest value	KSC which has the strongest value	
Task 1	3	4	/	**Case 4**
Task 2	3	3	/	**Case 4**
Task 3	3	1	6	**Case 4**
Task 4	3	5	/	**Case 4**
Task 5	2	6	/	
Task 6	3	9	/	**Case 4**
TREND				

Figure 30 Case 4- an example: MaxKSCenablesT matrix to extract the strongest task enabler

4.7 Summary and Discussion

This chapter discusses specification, conceptualization, and formalization of the WoW domain. The specification of the WoW domain results in choosing ISCO and KldB as the international and national (German) standards, respectively, to model the Job-Know Ontology. The main concepts of this domain include *Job*, *Task,* and *Job-KSC* concepts. Further, the super-role of *requires()* is defined to make the role between a task and the required KSCs. This role is detailed based on the *DD*, which determines the demand degree of a task and KSC. To instantiate the WoW domain, eight matrices are defined, where WoW-M1 and WoW-M2 should be filled by KA based on knowledge of KP. Finally, the cases, which are inferred from the role(s) between tasks and Job-KSCs, are described.

The scope of the WoW domain is based on ISCO and KldB; however, the proposed model should be further extended to the other European states (first priority group), and also to non-European states (second priority group). The author recommends focusing on the aforementioned priority group, as the European countries already provide national standards for their occupations or are proceeding to do so, and to a great extent they follow recommendations of the European Commission, which consequently increases the potential of matching. One of the main challenges, when the scope is extended to the other European states, is the diversity of languages adding difficulty in a common understanding of the terms. The matching between European Commission standards and the national ones, as well as matching between national standards, may raise an opportunity to facilitate the exchange of job holders and support mobility of skills workers across Europe. Matching with non-European states will also facilitate the integration of non-European skill workers in the European job market. Such an approach will be beneficial to all European states especially due to the demographic changes and the increasing demands to employ non-European skills workers.

Considering the technological, societal and economic dynamics in the WoW, the changing pace of jobs and/or tasks is relatively high. It is, therefore, essential to identify a systematic way to not only acquire and represent the currently defined tasks which should be performed right now, but also to foresee the emerging future demands promptly and have the appropriate actions to provide the prerequisites in adequate time. This challenge is discussed in Chapter 6.

5 WoE Domain of Job-Know Ontology

5.1 Overview

In this thesis, WoE is the encapsulation of learning fields and learning units, taught by teachers or trainers and learned by learners to obtain KSCs (learning outcomes) within and/or at the end of the learning process. In the context of VET, learners obtain specific learning outcomes, enabling them to respond to the demands of WoW by demonstrating the required KSCs. In this way, WoE is the supplier of KSCs for WoW.

This chapter presents the systematic way to semantically represent the WoE domain and to infer the supplies of WoE. The structure of this chapter is based on the phases of DP-1 described in Chapter 3.7. First, the WoE domain is specified in Chapter 5.2, second it is conceptualized in Chapter 5.3, and finally formalized in Chapter 5.4. Further, the implementation results are presented in Chapter 7 by exemplifying a domain-specific use-case of nursing.

5.2 Specification of WoE Ontology

As specified in Chapter 3.6. *Specification*-DP1, the WoE scope of the Job-Know Ontology is based on ISCED and EQF, particularly using German Qualification Framework (DQR)[31]. In the following, both the standard and the frameworks are described.

5.2.1 International Standard Classification of Education (ISCED)

ISCED[32] is designed and maintained by UNESCO[33] to serve "as an instrument suitable for assembling, compiling, and presenting statistics of education both within individual countries and internationally" (UNESCO Institute for Statistics 2014). ISCED has been updated over the past three decades, resulting in three versions being available: ISCED-1970, ISCED-1997, and ISCED-2011(valid version and used in this study). ISCED has two dimensions: i) level of education and ii) fields of education.

The first dimension of ISCED determines eight levels (nine if including early childhood education) of education: 0-Early childhood education, 1-Primary education, 2-Lower secondary education, 3-Upper secondary education, 4-Post-secondary non-tertiary education, 5-

[31] In German: Deutschen Qualifikationsrahmen

[32] This sub-chapter 5.2.1 is mainly written based on (UNESCO Institute for Statistics 2014)

[33] Refers to United Nations Educational, Scientific and Cultural Organization

Short-cycle tertiary education, 6-Bachelor or equivalent, 7-Master or equivalent, and 8-Doctoral or equivalent. The ISCED-1997 education levels, which were structured in six levels, were mapped to the four skill levels of ISCO-08 (cf. Chapter 4.2.1). Table 11 shows the correspondence between ISCO-08 and ISCED-2011 via ISCED-1997 to identify the level of education needed to perform a job.

Table 11 Correspondence between ISCO-08 and ISCED-2011 via ISCED-1997 adopted from (UNESCO Institute for Statistics 2014)

ISCO-08 Skill Level	***ISCED-1997***	***ISCED-2011***
skill level 1	*level 1*	*level 1(Primary education)*
skill level 2	*level 2*	*level 2 (Lower secondary education)*
	level 3	*level 3 (Upper secondary education)*
	level 4	*level 4 (Post-secondary non-tertiary education)*
skill level 3	*level 5b*	*level 5 (Short-cycle tertiary education)*
	level 5a + 5b	*level 6 (Bachelor or equivalent)*
skill level 4	*level 5a*	*level 7 (Master or equivalent)*
	level 6	*level 8 (Doctoral or equivalent)*

The latter dimension of ISCED clusters the education fields based on the similarities in the theoretical knowledge and the purpose of learning (i.e. main subject matter). ISCED has 4-digit schema (cf. Figure 31) to identify 11 broad fields denoted by the first-2 digits from the left (X_1, X_2), 29 narrow fields denoted by the third digit from the left digit (X_3), and about 80 detailed fields of education and training denoted by the fourth digit from the left (X_4). The programmes and qualifications for the education fields are identified at the bottom level by the detailed fields.

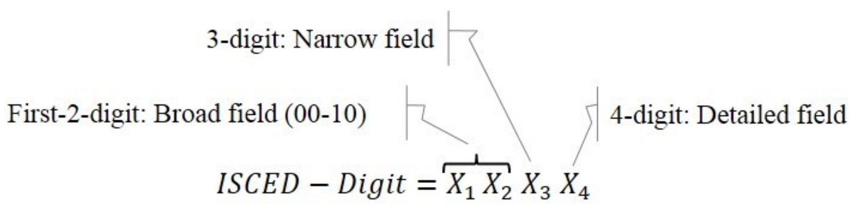

Figure 31 Four-digit Schema of ISCED-2011 - Adopted from (UNESCO Institute for Statistics 2014)

5.2.2 European Qualification Framework (EQF)

EQF was adopted by the European Parliament and the Council in 2008 (European Parliament, Council of the European Union 2008). EQF is built upon the qualification of EU countries towards facilitating mobility of learners and workers and supporting lifelong learning across Europe. EQF defines KSCs by indicating the learning outcomes in eight levels

(European Parliament, Council of the European Union 2008). The learning outcome is considered as an umbrella term encompassing KSCs (European Commission 2010). Knowledge is described as theoretical and/or factual, while skills are described as the use of logical, intuitive and creative thinking (cognitive), with the use of methods, materials, tools, and instruments (practical) (European Parliament 2008). In this context, competence is described as responsibility and autonomy (European Commission 2010). In fact, EQF shifts the focus from input-oriented to outcome-oriented results. Both EQF and ISCED have defined their levels of education based on the complexity of knowledge or problem. However, the method of structuring ISCED and EQF are not similar. While the former is based on "classifying the work of statistical experts and statistical criteria", the latter is based on a broad discussion on learning outcome with strong involvement of political stakeholders (Schneeberg 2009), (Cedefop, The Shift to Learning Outcomes: Policies and Practices in Europe 2009).

Furthermore, the EU countries are developing and/or have developed their own National Qualification Framework (NQF) based on EQF (Cedefop 2015). In particular, Germany established the German Qualification Framework (DQR)[34], which mainly concentrates on competences. It defines a four-pillar structure where i) knowledge and ii) skills are clustered as professional competence, and iii) social and iv) autonomy as personal competence (German Qualifications Framework (DQR) 2011).

5.3 Conceptualization of WoE Domain

The WoE domain consists of two dimensions of i) Learning Unit and ii) Learning Outcome. To define these two dimensions the numbers of the concepts are elaborated in WoE domain of the Job-Know Ontology, as described in the following. Firstly, in order to have a common understanding, the terms which are used to conceptualize WoE domain of the Job-Know Ontology are defined. Table 12 is the complement to Table 7 to complete the given Glossary.

Table 12 Job-Know Glossary - Part of WoE

ID	***Term***	***Definition***	***Source***
G7	*Learning field*	*An education programme or qualification, which covers a broad domain, branch or area of content*	(UNESCO Institute for Statistics 2014)

[34] In German: Deutschen Qualifikationsrahmen (DQR)

ID	***Term***	***Definition***	***Source***
G8	*Curriculum*	*The specification for learning objectives, content, teaching methodology, and material, as well as arrangements for training teachers and trainers*	(Cedefop 2008)
G9	*Learning unit*	*The component of a qualification, consisting of a coherent set of knowledge, skills, and competences called learning outcome, that can be assessed and validated*	(Cedefop 2008)
G10	*Learning Out-come*	*"What a learner knows, understands and is able to do on completion of a learning process", which is defined in terms of knowledge, skills, and com-petence*	(European Commission 2010)

5.3.1 Conceptualization of Learning Field, Curriculum and Learning Unit

To conceptualize what learning fields are taught at educational institutions, ISCED is taken into account. With respect to the structure of ISCED, three hierarchal concepts are defined as Broad Field (e.g. X_1X_2 = 09-Health and welfare), Narrow Field (e.g. X_3 = 1-Health), and Learning Field (e.g. X_4 = 3-Nursing and midwifery).

To teach a Learning Field there should be a curriculum, although there is more than one curriculum to teach a single field. There is also the list of the learning units taught in the frame of the curricula, for example, to teach 0913-Nursing and Midwifery in Germany, there are different curricula[35] established by the German federal states such as NRW-Curriculum[36] to learn nursing. The learning units are extracted from the curricula and are defined as the smallest element of the curriculum, such as "Skin and Body"[37] which includes goal, field-specific content, relevant contents in the other fields, and learning hour.

There is a (part-whole) role entitled *consistsOf()*, which relates the super-concepts of ISCED to its own sub-concepts. Further, the role of *hasCurriculum()* relates the *Learning Field* to the *Curriculum* concepts. Finally, the *Curriculum* Concept is related to the *Learning Unit* concept via the role of *consistsOfLU()*. Figure 32 illustrates the concepts and roles described above.

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[35] In Germany, Nursing Act sets the nursing education in general, but the federal states are responsible to implement their curricula within the guidelines as well as the rules and regulations for the training and general provisions of exams (KrPflG 2003).

[36] Directive for training in health care and nursing, as well as in health and childcare Affairs of the State of North Rhine-Westphalia (Oelke 2003).

[37] In German: Haut und Körper pflegen

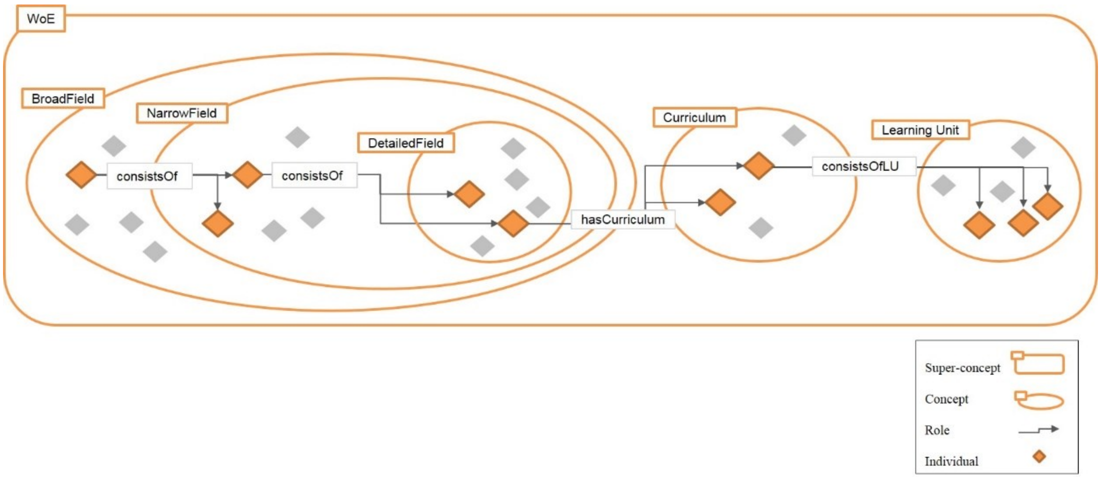


Figure 32 WoE domain to identify Curriculum and Learning Unit Concepts and Roles

The learning unit has certain characteristics, which are described as: the unit type, learning hour required to spend on the learning unit, assessment type, reading list, and learning place. The characteristics are defined as the sub-concepts of the *Learning Unit* concept and instantiated as follows:

- Unit type is subdivided into the discussion, fieldwork, hands-on, lecture, lesson, placement, practicum, presentation, project, seminar, and tutorial.
- Learning hour is subdivided into contact hour, self-study hour, hands-on hour, and assessment hour.
- Assessment type is subdivided into the assignment, report, dissertation, examination, field-work, log-book, mentoring, oral examination, oral exercise, placement, portfolio, practical, presentation, project, diary report, research, paper seminar, paper, thesis, transcription, workbook, workshop, written exercise, and written test.
- Reading list is subdivided into book, journal, website, and slide.

5.3.2 Conceptualization of Learning Outcome

The aim of learning a unit is to obtain specific KSCs which are consolidated as learning outcomes. In particular, (accumulation of certain) learning unit(s) qualifies learners to obtain the target learning outcomes. The list of learning outcomes of a field shows that a learning outcome is obtained sometimes not only by learning one unit, but also that (various/different) sort of learning units are needed to obtain a specific learning outcome. In other words, each learning unit may qualify the learner to obtain the learning outcome, and gradually to reach the required learning outcome for the field at the end of the learning process. A supply degree

(*SD*) is, therefore, defined to identify how much one learning unit can qualify learners to obtain one specific learning outcome. The *SD* is distinguished into four degrees detailed by Table 13.

Table 13 Supply Degree (SD) in detail

SD	***Description***	***Value***
Strong dependency	*Learning unit* l_h *qualifies strongly to obtain the learning outcome* c_g	*3*
Moderate dependency	*Learning unit* l_h *qualifies moderately to obtain the learning outcome* c_g	*2*
Weak dependency	*Learning unit* l_h *qualifies weakly to obtain the learning outcome* c_g	*1*
No dependency	*Learning unit* l_h *does not qualify to obtain the learning outcome* c_g	*0*

Based on the categorization of the EQF, the *Learning Outcome* concept is subdivided into the sub-concepts of *Knowledge*, *Skills,* and *Competence* (cf. Table 7 – G4, G5 and G6 respectively).

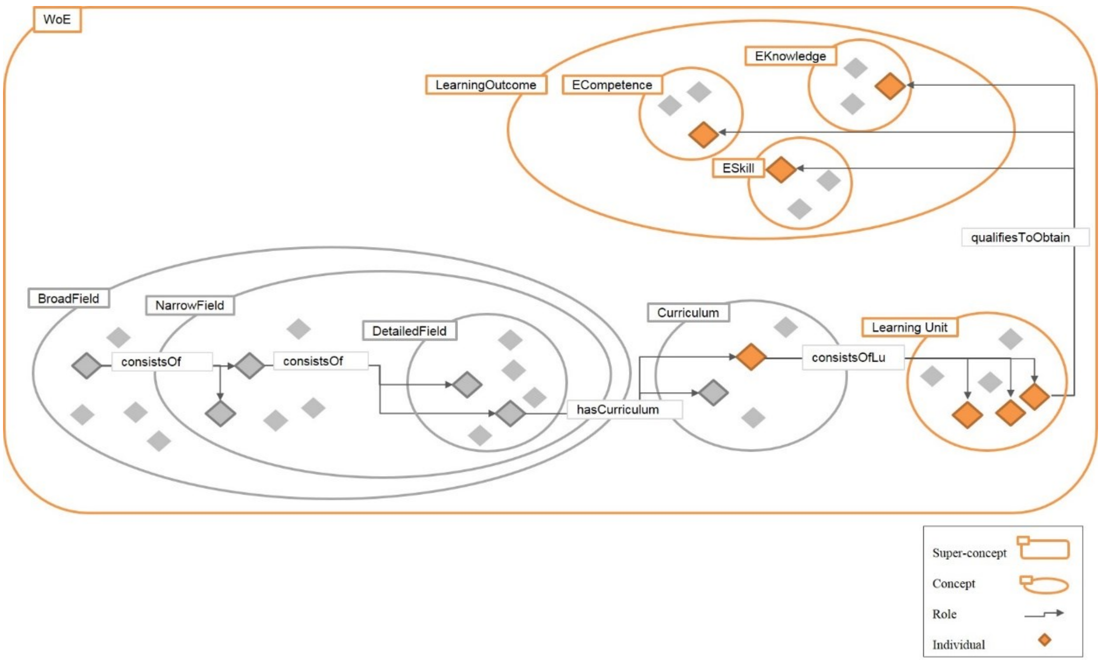


Figure 33 Learning Unit and Learning Outcome Concepts and their Roles

The role of *qualifiesToObtain()* relates the *Learning Unit* concept to the *Learning Outcome* concept. The super-role of *qualifiesToObtain()* consists of the sub-roles, which are specified by the *SD* of a learning unit and a learning outcome based on the description given in Table 13. The top part of Figure 33 marked in orange presents the concepts of *Learning Unit*, *Learning Outcome,* and their relation.

5.4 Formalization of T-Box of WoE Ontology

This sub-chapter formalizes the WoE domain based on the definitions and descriptions provided in the conceptualization phase. In the following, firstly the concepts of WoE are formalized and later the roles. The atomic concepts and roles are marked with (A), while the complex ones are marked with (C).

5.4.1 Concepts of WoE Domain

To formalize the concepts of the WoE domain, firstly the atomic concepts are introduced and based on them, the complex concepts are elaborated.

- *Learning Unit* is an atomic concept representing what should be learned. Learning units qualify (learners) to obtain the learning outcome (cf. Table 12 – G9).

$$LearningUnit(lu) \subset qualifiesToObtain.LearningOutcome(lo)$$

(WoE-D1-A)

- As described earlier, the learning unit has a certain characteristic that identifies some details of the unit.

$$LearningUnitcharacteristic(lu) \equiv \exists_{=1} needsHour.LearningHour(lh) \vee isDeliveredthrough.UnitType(ut) \vee \exists_{\geq 1} isAssessedthrough.AssessmentType(at) \vee \exists_{\geq 1} hasReadingList.ReadingList(rl) \vee \exists_{\geq 1} hasLearningPlace.LearningPlace(lp)$$

(WoE-D2-C)

- The sub-concepts of the *Learning Unit Characteristic* have specific individuals mentioned below.

$$LearningHour(lh) = \{ contactHour, selfstudyHour, handsonHour \text{ and } assessmentHour\}$$

$$UnitType(ut) = \{discussion, fieldwork, hands\ on, lecture, lesson, placement, practicum, presentation, project, seminar, \text{and } tutorial\}$$

$$AssessmentType(at) = \{assignment, report, dissertation, examination, fieldwork, logbook, mentoring, oral\ examination, oral\ exercise, placement, portfolio, practical, presentation, project, diary\ report, research, paper\ seminar, paper, thesis, transcription, workbook, workshop, written\ exercise, \text{and } written\ test\}$$

$$ReadingList(rl) = \{book, journal, website, slide\}$$

$$LearningPlace(lp) = \{workplace, learningOrganization, mixedPlace\}$$

(WoE-D2.1)

- Each *Curriculum* includes learning units (cf. Table 12 – G9)

$$Curriculum(cu) \equiv \exists_{\geq 1} consistsof.LearningUnit(lu)$$

(WoE-D3-C)

- *Learning field* is an education programme or qualification, which includes specified curriculum and has a unique ISCED digit (cf. Table 12 – G7).

$$LearningField(lf) \equiv \exists_{\geq 1} hasCurriculum.Curriculum(cu) \wedge hasLearningStyle.LearningStyle(lf) \wedge \exists_{=1} hasDigit.ISCEDdigit(id)$$

(WoE-D4-C)

- *ISCED digit* is a 4-digit schema which represents three categories of broad field denoted by the first-2 digits from the left, narrow field denoted by the third digit from the left digit, and detailed field (Learning field) of education and training denoted by the fourth digit from the left (UNESCO Institute for Statistics 2014).

$$ISCEDdigit(id) \equiv \exists_{=1} hasFirstDigit.BroadField(bfi) \wedge \exists_{=1} hasSecondDigit.NarrowField(nfi) \wedge \exists_{=1} hasLastDigit.DetailedField(dfi)$$

(WoE-D5-C)

- *Learning Outcome* consists of Knowledge, Skill, or Competences. *Learning Outcome* requires *Learning Unit* to be obtained (cf. Table 12 – G8).

$$LearningOutcome \equiv consistsOf.\big(EKnowledge(ek) \vee ESkill(ek) \vee ECompetence(ek)\big) \wedge requiresToBeObtained.LearningUnit(lu)$$

(WoE-D6-C)

- *Knowledge* is an atomic concept which groups the core knowledge elements required for a certain job (cf. Table 7 – G4).

$$EKnowledge(ek) \supset requiresToBeObtained.LearningUnit(lu)$$

(WoE-D7-A)

- *Skill* is an atomic concept which groups the ability to apply knowledge and use know-how to complete tasks and solve problems (cf. Table 7 – G5).

$$ESkill(es) \supset requiresToBeObtained.LearningUnit(lu)$$

(WoE-D8-A)

- *Competence* is an atomic concept which groups the ability to use knowledge, skills and personal, social and/or methodological abilities, in work or study situations and in professional and personal development (cf. Table 7 – G6).

$$ECompetence(ec) \supset requiresToBeObtained.LearningUnit(lu)$$

(WoE-D9-A)

5.4.2 Roles of WoE

In the following, the semantic relations that were conceptualized earlier are formalized. The atomic roles are marked with (A) and complex ones with (C).

- Learning Field and Curriculum is related via *hasCurriculum()* role.

(WoE-R1-A)

- *Curriculum* and *Learning Unit* is related via *consistsOfLU()* role, which is atomic.

(WoE-R2-A)

- The relation between Learning Unit and Learning Outcome concepts are defined as *qualifiesToObtain()*, and its inverse *requiresToBeObtained()*, where the *SD* elaborates the sub-roles of *qualifiesToObtain-Not()* for *SD*=0, *qualifiesToObtain-Weakly()*for *SD*=1, *qualifiesToObtain-Moderately()* for *SD*=2, *qualifiesToObtain-Strongly()*for *SD*=3. The default role is *qualifiesToObtain-Not()*, which means there is no relation between the learning unit and the learning outcome.

$$qualifiesToObtain - Strongly(lu, lo) \vee qualifiesToObtain - Moderately(lu, lo) \vee qualifiesToObtain - Weakly(lu, lo) \vee qualifiesToObtain - Not(lu, lo) \supset qualifiesToObtain\ (lu, lo)$$

(WoW-R3-C)

5.5 Instantiation of WoE Domain

Up to this point, the WoE part of the T-Box (i.e. concepts and roles) of the Job-Know Ontology has been formalized. Following is a discussion on how the concepts are instantiated and populated with respect to an education. The matrices (WoE-M1 – WoE-M7) are introduced to identify the details.

5.5.1 Visualization of an A-Box

As described earlier, a learning unit qualifies a learner to obtain specified KSCs, which is the outcome of the learning process. Therefore, the KSCs supplied by each learning units are specified and grouped based on the eight levels of EQF in three concepts of *Eknowledge*, *Eskill* and *Ecompetence*. Finally, each learning unit of the curriculum should be related to their outcomes and its *SD* should be identified.

Notably, there can be differentiations between the learning units of the curricula of a field in terms of content in depth and breadth, which as a consequence, together provide the learning outcomes in different supply degrees. Thus, the learning outcomes of the different curricula of a field might not be quite the same. This differentiation results in supplying the strong or weak outcomes.

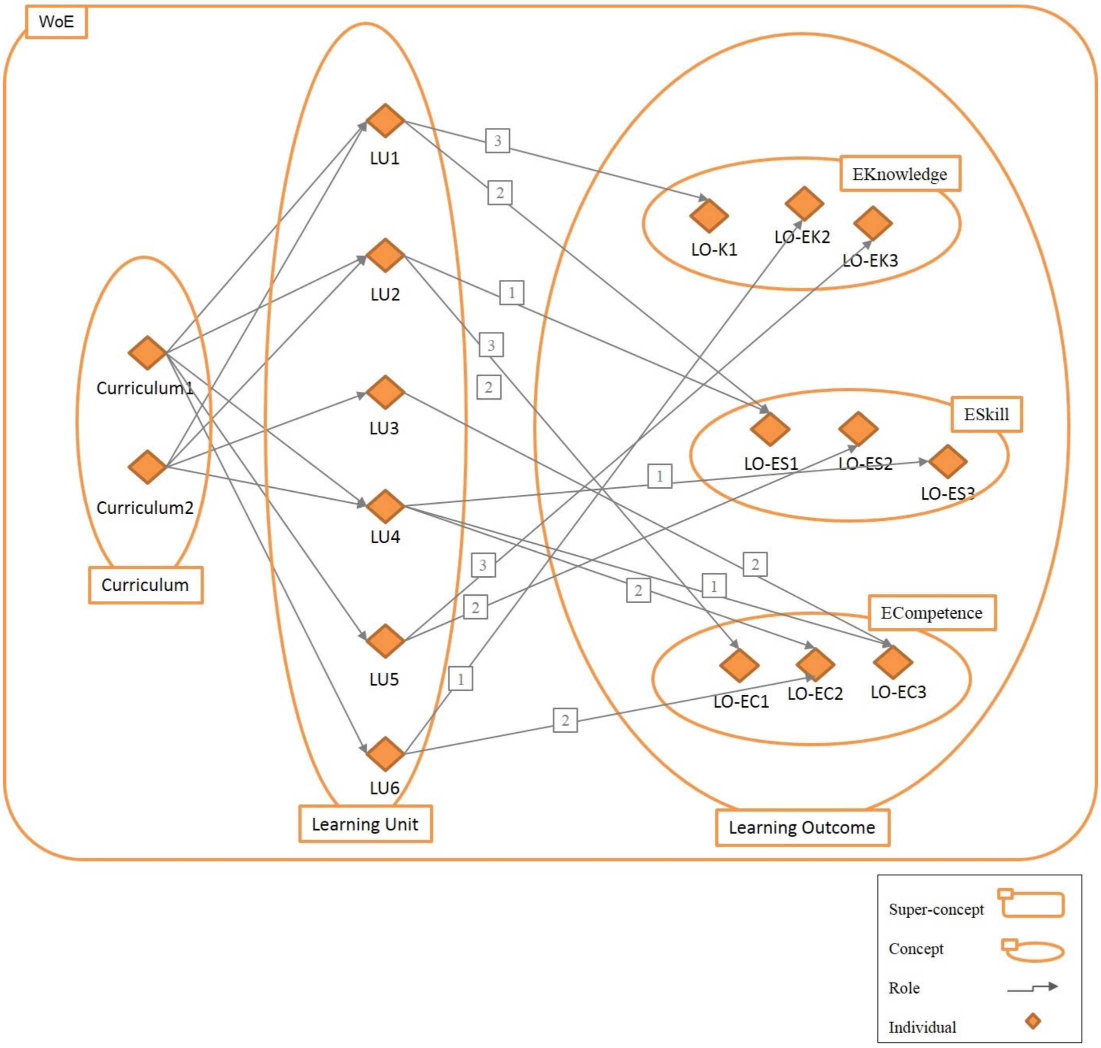


Figure 34 Part of A-Box of Job-Know Ontology

Figure 34 exemplifies the A-box of WoE domain and visualizes the roles between the individuals of the *Curriculum*, *LearningUnits* and *LearningOutcome* concepts. The orange ovals represent the concepts, the diamonds represent the individuals, and the lines illustrate the roles. The value on the roles between the learning units and the learning outcomes are based on *SD* (cf. Table 13), which specify the sub-roles of *qualifiesToObtain()*. For instance, there are a number of learning units (noted as LU), which may belong to one curriculum (noted Curriculum1). The super-role between learning units and learning outcomes is *qualifiesToObtain()*, where *SD* specifies the supply degree of the learning unit and learning outcome (e.g. LU1 *qualifiesToObtain- Moderately* LO-K1 with supply degree of 3).

5.5.2 Learning Unit-Learning Outcome Matrix

The role of *qualifiesToObtain()* between learning unit, learning outcome, and *SD* value creates the *Learning Unit-Learning Outcome* (*LuLo*) matrix. The matrix has *h* rows referring to the learning units defined in a respected curriculum, and *g* columns referring to the learning outcomes obtained via learning the units. The cells of the *LuLo* matrix represent *SD* of the learning units and their outcomes. The given value of the cells is identified as $SD \in \{0, 1, 2, 3\}$ (cf. Table 13). WoE-M1 represents the learning units (i.e. in rows), the learning outcome (i.e. in columns), and the *SD* via the sub-role of *qualifiesToObtain()*.

$$LuLo_{h\times g} = \begin{bmatrix} qualifiesToObtain(lu_1, lo_1) & \cdots & qualifiesToObtain(lu_1, lo_j) \\ \vdots & \ddots & \vdots \\ qualifiesToObtain(lu_i, lo_1) & \cdots & qualifiesToObtain(lu_i, lo_j) \end{bmatrix}_{h\times g}$$

(WoE-M1)

The $LuLo_{h\times g}$ matrix is firstly filled out based on the sub-roles defined by WoE-R3, which refers to the type of the role, before it is transferred to the numerical matrix. For example, the role of *qualifiesToObtain-Moderately*(lu_1,lo_1) between task lu_1 and Learning Outcome lo_1 is identified by (3) in the matrix. WoE-M1.1 exemplifies the $LuLo_{6\times 9}$ matrix, data is taken from Figure 34.

$$LuLo_{6\times 9} = \begin{bmatrix} 3 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 3 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 2 & 1 \\ 0 & 0 & 3 & 0 & 2 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 2 & 0 \end{bmatrix}_{6\times 9}$$

(WoE-M1.1)

5.5.3 Sum of Learning Outcome-Curriculum Matrix

Given each cell of the *LuLo* matrix (WoE-M1), which are not filled out with 0, the value of 1 otherwise 0, then the sum of the rows of a column of *LuLo* matrix identifies how many learning units are included to qualify learners to obtain a learning outcome. In this way, the *SumLo* matrix is constructed (cf. WoE-M2) with *h* columns (i.e. the learning outcomes identified in this learning field), and one row.

$$SumLo_{1\times g} = \left[\sum_{h=1}^{h=Number\ of\ Lu} qualifiesToObtain(lu_h, lo_1) \quad \dots \quad \sum_{h=1}^{h=Number\ of\ Lu} qualifiesToObtain(lu_h, lo_g) \right]$$

(WoE-M2)

WoE-M2.1 exemplifies the *SumLo* matrix based on the values given by WoE-M1.1.

$$SumLo_{1\times 9} = [1 \quad 1 \quad 1 \quad 2 \quad 1 \quad 1 \quad 1 \quad 2 \quad 2]$$

(WoE-M2.1)

5.5.4 Sum of Learning Outcome-Learning Unit Matrix

In another way, given each cell of the *LuLo* matrix (WoE-M1) not filled out with 0, the value of 1, the sum of the columns of a row identifies how many learning outcomes are obtained by learning a specific learning unit of the curriculum. The *SumLu* (cf. WoE-M3) matrix is constructed with *h* rows (i.e. the learning units should be learned in this learning field) and one column.

$$SumLu_{h\times 1} = \begin{bmatrix} \sum_{g=1}^{g=Number\ of\ Learning\ Outcome} qualifiesToObtain(lu_1 lo_g) \\ \vdots \\ \sum_{g=1}^{g=Number\ of\ Learning\ Outcome} qualifiesToObtain(lu_h lo_g) \end{bmatrix}$$

(WoE-M3)

WoE-M3.1 exemplifies the *SumLu* matrix based on the values given by WoE-M1.1.

$$SumLu_{6\times 1} = \begin{bmatrix} 2 \\ 2 \\ 1 \\ 3 \\ 2 \\ 2 \end{bmatrix}$$

(WoE-M3.1)

5.5.5 Strongest Learning Outcome-Curriculum Matrix

The *MaxLoObtainsFC* matrix is a 2-dimensional (2-D) matrix, which is established based on the $LuLo_{h\times g}$ matrix to represent:

- 1-D: the maximum value of the rows of a column of $LuLo_{h\times g}$ matrix that identifies which learning outcome can be obtained more than other learning outcomes by learning the given curriculum. The data is extracted by applying the function of $\max_{h\in number\ of\ learning\ units} SD_{h\times g}$.
- 2-D: the index of the row (learning unit) which qualifies (learners) to obtain the learning outcome with the maximum value (1-D) via applying the function of $\operatorname{argmax}_{h\in number\ of\ learning\ units} SD_{h\times g}$.

The number of the rows (*m*) of the *MaxLoObtainsFC* shows that there is more than one learning unit which has the maximum value. The WoE-M4 represents the $MaxLoObtainsFC_{m\times g}$ matrix.

$$MaxLoObtainsFC_{m\times g} = \left[\left(\max_{h\in number\ of\ Lu} SD_{h\times 1},\ \operatorname{argmax}_{h\in number\ of\ Lu} SD_{h\times 1}\right) \cdots \max_{h\in number\ of\ Lu} SD_{h\times g},\ \operatorname{argmax}_{h\in number\ of\ Lu} SD_{h\times g}\right]$$

(WoE-M4)

WoE-M4.1 exemplifies the *MaxLoObtainsFC* matrix based on the values given by WoE-M1.1.

$$MaxLoObtainsFC_{2\times 9} = \begin{bmatrix} (3,1) & (1,6) & (3,2) & (3,4) & (1,4) & (3,3) & (2,3) & (2,4) & (3,6) \\ - & - & - & - & - & - & - & (2,6) & - \end{bmatrix}$$

(WoE-M4.1)

5.5.6 Strongest Learning Outcome-Learning Unit Matrix

The *MaxLoObtainsFLu* matrix is a 2-dimensional (2-D) matrix which is established based on the $LuLo_{h\times g}$ matrix (WoE-M1) to represent:

- 1-D: the maximum value of the columns of a row of $LuLo_{h\times g}$ matrix that identifies which learning outcome is obtained more than other learning outcomes by learning the specific learning unit via applying the function of $\max_{g\in number\ of\ learning\ outcomes} SD_{h\times g}$.
- 2-D: the index of the column (learning outcome) obtained from the specific learning unit with the maximum value (1-D) via applying the function of $\operatorname{argmax}_{g\in number\ of\ learning\ outcomes} SD_{h\times g}$.

The number of the column (k) of the *MaxLoObtainsFLu* shows there is more than one learning outcome with the maximum value. The WoE-M5 represents the *MaxLoObtainsFLu* $_{h\times k}$ matrix.

$$MaxLoObtainsFLu_{h\times k} = \begin{bmatrix} (\max_{g\in number\ of\ learning\ outcomes} SD_{1\times g}, \operatorname{argmax}_{g\in number\ of\ learning\ outcomes} SD_{1\times g}) \\ \vdots \\ (\max_{g\in number\ of\ learning\ outcomes} SD_{h\times g}, \operatorname{argmax}_{g\in number\ of\ learning\ outcomes} SD_{h\times g})) \end{bmatrix}$$

(WoE-M5)

WoE-M5.1 exemplifies the *MaxLoObtainsFLu* matrix based on the values given by WoE-M1.1.

$$MaxLoObtainsFLu_{6\times 2} = \begin{bmatrix} (3,1) \\ (3,7) \\ (2,9) \\ (2,9) \\ (3,3) \\ (2,8) \end{bmatrix}$$

(WoE-M5.1)

5.5.7 Curriculum-Learning Unit Matrix

To represent the role between the curricula of the field and the learning units, the matrix of *CLu* (WoE-M5) is defined, where each row represents a curriculum and each column represents a learning unit of a given curriculum. If there is a role between the curriculum cu_x and learning unit lu_y, the value 1 will be inserted in the respected cell of the matrix ($cu_x lu_y$), or else 0.

$$CLu_{n\times h} = \begin{bmatrix} consistsOfLU(cu_1, lu_1) & \cdots & consistsOfLU(cu_1, lu_i) \\ \vdots & \ddots & \vdots \\ consistsOfLU(cu_n, lu_1) & \cdots & consistsOfLU(cu_n, lu_i) \end{bmatrix}_{n\times h}$$

(WoE-M6)

WoE-M4.1 exemplifies the *CLu* matrix (WoE-M5), and, in particular, shows two curricula (rows) and six learning units (columns).

$$CLu_{2\times 6} = \begin{bmatrix} 1 & 1 & 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 0 & 0 \end{bmatrix}_{2\times 6}$$

(WoE-M6.1)

5.5.8 Curriculum-Learning Outcome Matrix

The multiplication of the matrices $CLu_{n\times h}$ and $LuLo_{h\times g}$ provides the value of the learning outcomes obtained by learning each curriculum of the field in total. $CLo_{n\times g}$ is the resultant matrix (WoE-M6).

$$CLo_{n\times g} = \begin{bmatrix} consistsOfLU(cu_1, lu_1) & \cdots & consistsOfLU(cu_1, lu_i) \\ \vdots & \ddots & \vdots \\ consistsOfLU(cu_n, lu_1) & \cdots & consistsOfLU(cu_n, lu_i) \end{bmatrix}_{n\times h}$$
$$\times \begin{bmatrix} qualifiesToObtain(lu_1, lo_1) & \cdots & qualifiesToObtain(lu_1, lo_j) \\ \vdots & \ddots & \vdots \\ qualifiesToObtain(lu_i, lo_1) & \cdots & qualifiesToObtain(lu_i, lo_j) \end{bmatrix}_{h\times g}$$
$$= \begin{bmatrix} CqualifiesToObtain(cu_{1_1}, lo_1) & \cdots & CqualifiesToObtain(cu_1, lo_j) \\ \vdots & \ddots & \vdots \\ CqualifiesToObtain(cu_n, lo_1) & \cdots & CqualifiesToObtain(cu_n, lo_j) \end{bmatrix}_{n\times g}$$

(WoE-M7)

WoE-M7.1 exemplifies the $CLo_{2\times 6}$ matrix based on the values given WoE-M1 and WoE-M6.1.

$$CLu_{2\times 6} \begin{bmatrix} 1 & 1 & 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 0 & 0 \end{bmatrix}_{2\times 6} \times LuLo_{6\times 9} \begin{bmatrix} 3 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 3 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 2 & 1 \\ 0 & 0 & 3 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 \end{bmatrix}_{6\times 9}$$
$$= CLo_{2\times 6} \begin{bmatrix} 3 & 1 & 3 & 3 & 2 & 1 & 3 & 4 & 1 \\ 3 & 0 & 0 & 3 & 0 & 1 & 3 & 2 & 3 \end{bmatrix}_{2\times 6}$$

(WoE-M7.1)

5.6 Inferences of WoE Cases

This sub-chapter describes the cases inferred based on the T-Box and A-Box and specifically defined for the WoE domain. The cases also provide answers to the CQs (cf. Chapter 3.3). The condition, description, and formalization of cases are detailed as follows.

***Case 1**: Unique Learning Outcome*

Description: Only lu_a qualifies (learners) to obtain uniquely lo_b. This means lo_b is a unique learning outcome obtained from this curriculum, and that none of the other learning units of this curriculum qualifies (learners) to obtain lo_b. This result inferred from the *SumLo* matrix (WoE-M2) presents the number of the learning outcomes that are obtained by learning this curriculum.

$$\exists_{=1} lu_a, lo_b\ \forall lu\ LearningUnit(lu_a) \wedge LearningOutcome(lo_b) \wedge qualifiesToObtain(lu_a, lo_b) \bigwedge_{h \in number\ of\ Learning\ units,\ \ h \neq a} qualifiesToObtain - Not(lu_h, lo_b) \supset UniqueLearningOutcome(lo_b)$$

(WoE-I1)

For example, according to WoE-M2.1 learning outcomes of lo_1, lo_2, lo_3, lo_5, lo_6 and lo_7 are the unique learning outcome for this curriculum. Figure 35 illustrates the results.

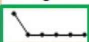
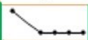
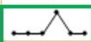
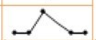
LuLo Matrix	LO1	LO2	LO3	LO4	LO5	LO6	LO7	LO8	LO9
Learning Unit 1	3	0	0	2	0	0	0	0	0
Learning Unit 2	0	0	0	1	0	0	3	0	0
Learning Unit 3	0	0	0	0	0	0	0	0	2
Learning Unit 4	0	0	0	0	0	1	0	2	1
Learning Unit 5	0	0	3	0	2	0	0	0	0
Learning Unit 6	0	1	0	0	0	0	0	2	0
Trend									
SumLo	**1**	**1**	**1**	**2**	**1**	**1**	**1**	**2**	**2**
	Case 1	**Case 1**	**Case 1**		**Case 1**	**Case 1**	**Case 1**		

Figure 35 Case1- an example: the rows show the learning units, the columns show the learning outcomes, and the cells SD

***Case 2**: Unique Learning Unit Enabler*

- **Description:** Only lo_b is uniquely obtained from lu_a. This means lu_a just qualifies (learners) to obtain one learning outcome, which is lo_b. However, it is possible that the other learning units of this curriculum qualify learners to obtain this learning outcome as well. This result is inferred from the *SumLu* matrix (WoW-M3), which presents the number of learning outcomes obtained from learning the learning units.

$$\exists_{=1} lu_a, lo_b \forall lo\ LearningUnit(lu_a) \wedge LearningOutcome(lo_b) \wedge qualifiesToObtain(lu_a, lo_b) \bigwedge_{g \in number\ of\ learning\ outcome, g \neq b} qualifiesToObtain - Not\left(lu_a, lo_g\right) \supset UniqueLearningUnit(lu_a)$$

(WoE-I2)

For example, according to WoE-M3.1 the lu_3 uniquely qualifies learners to obtain lo_9. Figure 36 illustrates the results.

LuLo Matrix	LO1	LO2	LO3	LO4	LO5	LO6	LO7	LO8	LO9	TREND	SumLu	
Learning Unit 1	3	0	0	2	0	0	0	0	0		2	
Learning Unit 2	0	0	0	1	0	0	3	0	0		2	
Learning Unit 3	0	0	0	0	0	0	0	0	2		1	**Case 2**
Learning Unit 4	0	0	0	0	0	1	0	2	1		3	
Learning Unit 5	0	0	3	0	2	0	0	0	0		2	
Learning Unit 6	0	1	0	0	0	0	0	2	0		2	

Figure 36 Case2-an example: SumLu to extract the unique learning outcome

Case 3*: Strongest Curriculum Obtainer*

- **Description:** lo_b is obtained from learning this curriculum strongly, where there is a *qualifiesToObtain-Strongly()* role between lu_h and lo_b. The result is inferred from *MaxLoObtainsFC* matrix (WoW-M4).

$$\exists lu_a, Lo_b\ \forall lu\ learningUnit(lu_h) \wedge LearningOutcome(lo_b) \bigwedge_{h\in number\ of\ learning\ units} qualifiesToObtain - Strongly(lu_g, lo_b) \supset StrongestCurriculumObtainer(lo_b)$$

(WoE-I3)

For example, according to WoE-M4.1, the lo_1, lo_3, lo_4, lo_6, lo_9 are the strongest learning outcomes obtained from learning this curriculum. Figure 37 illustrates the results.

MaxLoObtainsFC Matrix	TREND	LO1	LO2	LO3	LO4	LO5	LO6	LO7	LO8	LO9
Strongest value of Lo-Cu1		3	1	3	3	1	3	2	2	3
		Case 3		**Case 3**	**Case 3**		**Case 3**			**Case 3**

Figure 37 Case 3- an example: MaxLoObtainsFC matrix to extract the strongest curriculum obtainer

Case 4*: Strongest Learning Unit Obtainer*

- Description: lo_b is obtained from learning the learning unit strongly, where there is *qualifiesToObtain-Strongly()* role between lu_a and lo_b. The result is inferred from *MaxLoObtainsFLu* Matrix (WoW-M5)

$$\exists lu_a, Lo_b\ \forall lo\ learningUnit(lu_a) \wedge LearningOutcome(lo_b) \bigwedge_{g\in number\ of\ learning\ outcomes} qualifiesToObtain - Strongly(lu_a, lo_g) \supset StrongestLearningUnitObtainer(lo_b)$$

(WoE-I4)

For example, according to WoE-M5.1, the lo_1 for lu_1, lo_3 for lu_5, lo_7 for lu_2 are the strongest learning outcomes, which are obtained from learning the aforementioned units. Figure 38 illustrates the results.

MaxLoObtainsFLu Matrix	Strongest value of Lo	Lo which has the strongest value	
Learning Unit 1	3	1	Case 4
Learning Unit 2	3	7	Case 4
Learning Unit 3	2	9	
Learning Unit 4	2	9	
Learning Unit 5	3	3	Case 4
Learning Unit 6	2	8	
Trend			

Figure 38 Case 4- an example: MaxLoObtainsFLu matrix to extract the strongest Learning Unit Obtainer

5.7 Summary and Discussion

This chapter discusses the specification, conceptualization, and formalization of the WoE domain. The specification of the WoE domain considers ISCED and EQF as the international standard and framework employed to model the WoE domain of the Job-Know Ontology. The concepts of this domain include *ISCED*, *Learning Field*, *Curriculum*, *Learning Unit*, and *Learning Outcome*. To instantiate the WoE, seven matrices are defined and should be filled out by KA based on knowledge of KP. The matrices are used to infer the WoE domain and identify four cases.

Like WoW, there is a potential to extend the scope of the WoE to the other European states (first priority group) that follow EQF, and also to the non-European states (second priority group). As mentioned earlier, one of the main challenges that should be tackled is the diversity of languages impacting on a common understanding of the terms and keywords. In addition, the priority groups deal with strategies for distribution of European skill workers who are educated in different education systems across Europe. These priority groups also examine the compatibility of education background of non-European skill workers with the education backgrounds in the hosted European states. This may assure proper integration of foreign skill workers in the European WoW.

The other challenge is that, in a changing environment, KSCs in demand are evolving over time. Therefore, there is a need to identify a systematic way to not only acquire and represent the learning units and their outcomes (which should be learned in WoE), but also to foresee the upcoming and future outcomes (which should be supplied to WoW) in the right time to respond to WoW's demands appropriately. To do so, firstly, the outcome of WoE should be time-independently modeled (i.e. static model) and later, the time factor needs to be added to the model (i.e. dynamic model). This part is detailed in Chapter 6.

6 Supply of WoE and Demand for WoW

6.1 Overview

WoE qualifies learners to obtain a set of KSCs defined as an outcome(s) of the learning process, e.g. in the context of VET. Schematically, WoE can be modeled as the learning system, in which "learning unit(s)" is the input(s), "learning" is the function, and "KSCs" is the outcome(s). On the demand side, WoW requires employees who possess the right KSCs to perform assigned tasks of the given jobs. If WoW is considered as the performing system, where "task(s)" and "KSCs" are the inputs, "performing a task by means of KSCs" is the function, and "performed task(s)" is the outcome(s). Bridging the WoE and WoW, WoC is a mediator where the output of WoE and input of WoW meet each other. In other words, the outcome of the learning system provided by WoE is KSC which, on the one hand, is possessed by learners and, on the other, is the input of the performing system of WoW that should be demonstrated by employees. The supply of WoE is "learning outcomes possessed by learners" and the demand of WoW is "KSC required by employees". Figure 39 illustrates the meeting point of WoE and WoW, where is WoC, KSC is in supply and demand.

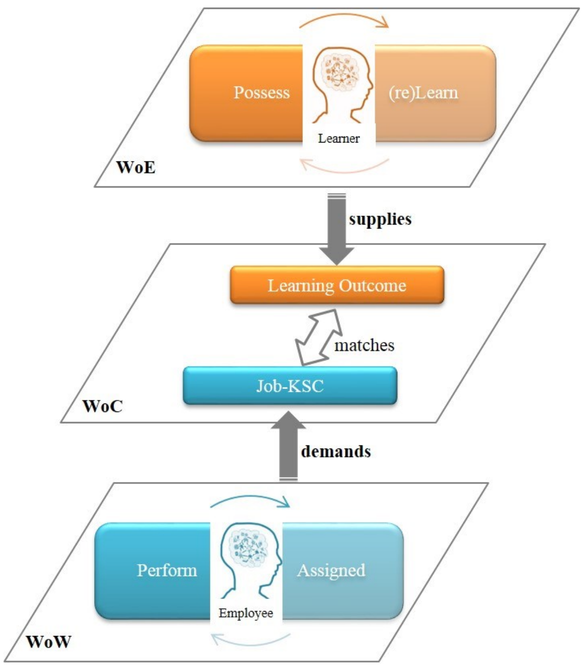


Figure 39 KSC is Meeting Point of WoW and WoE

Considering KSCs as the outcome of the learning system and input of the performing system, the main question is whether WoE and WoW reflect the consensus in the definition of KSCs. The lack of consensus reflected in defining KSCs may lead to a mismatch between what should be possessed by learners and what is expected and required by employers and vice versa. Ultimately the mismatch between supply and demand generates a ***skill imbalance problem,*** particularly for the knowledge-intensive and evolving job market.

The KSC supplied by WoE and the one required by WoW is in balance when supply meets what is demanded in quality and quantity, or, there is an imbalance with a gap, shortage, surplus and obsoleteness in supply-demand KSC. One of the main obstacle causing an imbalance of supply-demand KSC, is the lack and/or absence of communication between WoE and WoW. A systematic communication channel is, therefore, needed to tackle this obstacle. In this thesis, the communication channel is introduced as WoC. The goal of WoC is: i) to match the learning outcomes of the learning fields of the required KSCs in the WoW and vice versa, and ii) to define jobs which meet the KSCs possessed by learners (current or future job seekers). The former case refers to common mismatch problems e.g. in the European job market, and the latter is to avoid or manage over/under qualification problems.

In this chapter, firstly the “matching states” are described (i.e. defining the states where a balanced supply-demand KSC may properly take place), and the “domains alignment” to match KSC supplied by WoE and KSC demanded by WoW is discussed. Then the 3-D Space of Task, KSC and Learning Unit is introduced to explore what learning units are required to be able to perform certain tasks of a job. Further, the “time factor” to transform the static model to a dynamic environment (i.e. states of supply-demand KSC are studied and modeled over time) is considered. Finally, the relations between task and learning unit are inferred.

6.2 Matching State

Matching of the supply-demand KSC occurs in micro and macro levels. The **micro level** matching determines whether a KSC possessed by a job seeker is matched with KSC required by an employee or if there is an imbalance. In addition, it can imply whether the individual needs to compensate for the KSC gap and/or shortage, or if (s)he is over qualified to perform the job applied for. Thus, (s)he should be recommended for a job with a higher KSC match (KSCs required ↔ KSCs possessed). The micro level matching approach is used for finding optimal person-job-fit, benefitting both job seekers and employers. The micro level matching is studied in the literature, e.g. in (Fazel-Zarandi and Fox 2012), (Paoletti, Martinez-Gil and Schewe 2015), and (Guo, Alamudun and Hammond 2016). At the micro level, the problem of supply-demand matching can be described as follows:

Supply side: KSCs demonstrated by an individual, who learned a learning field as a learner and is now seeking a job,

Demand side: a job is announced and the employer seeks an employee who possesses the KSCs required to perform the job.

At the **macro level**, matching occurs between the learning outcomes of the learning fields supplied by WoE, and, the KSCs demanded by WoW to perform the job. On the one hand, macro matching examines whether or not the WoE supplies the right KSCs, in right time, based on the requirements of the WoW. On the other hand, it investigates whether or not WoW jobs have evolved based on the new and/or emerging KSCs that are (will be) possessed by learners and/or employees through their participation in VET and lifelong learning programmes. The result of macro matching identifies to what extent the WoW can potentially respond to the employment demands according to the development of the qualified job applicant population, who are trained by the WoE and possess the KSCs required by the WoW. Hence, individuals can find an optimal KSC-fit job and WoW can benefit from hiring KSC-fit employees.

Considering both micro and macro perspectives on matching and their relations, the focus of this thesis is on providing a semantic framework, known as Job-Know Ontology, for enhancing macro level matching WoW and WoE through WoC.

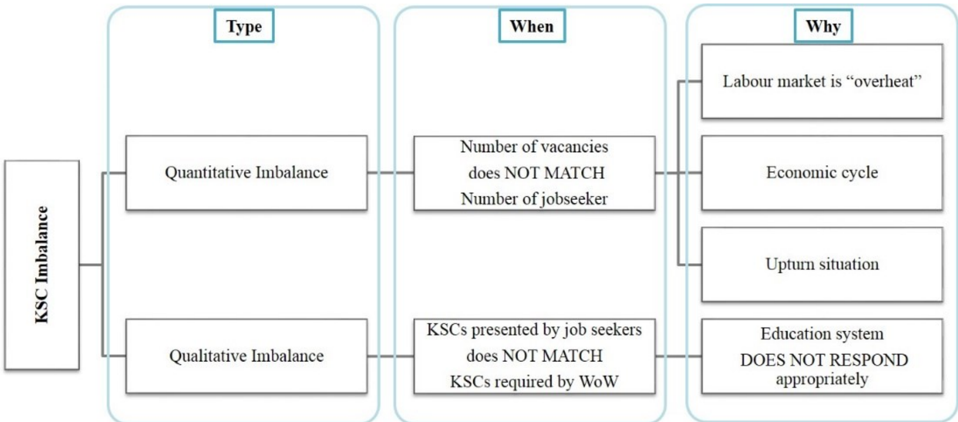


Figure 40 When and Why Qualitative and Quantitative Imbalance Occurs - Adopted from (Cedefop, ILO 2015)

With respect to the WoW policy terminology, the imbalance of supply-demand can be defined quantitatively or qualitatively (cf. Figure 40). The former occurs when the number of job vacancies does not match the number of job seekers, and the latter when the KSCs presented by job seekers do not demonstrate the KSCs required by the WoW (Gatelli and Johansen 2012), (Cedefop, ILO 2015). The latter situation is often rooted in the lack of a communication channel between the WoW and WoE. The WoE, thus, needs to reform to cope with the evolution and/or changes in the WoW's requirements, in right time and with the same pace. Notably, the WoE is not a follower of WoW: instead, they should communicate and learn from each other. Finally, it should be stressed that the quantitative analysis is also interrelated to the qualitative.

The cause of these problems is a lack of communication in the micro level, or in the communication of one job sector, or even the communication of one company with the WoE

Considering the matching between the KSCs supplied by a learning field and the KSCs demanded for a job, the qualitative analysis results in five states (cf. Figure 41) (Cedefop 2015), (Shah and Burke 2003):

1. **KSC Gap:** the job requires a KSC, which is not the outcome of any learning unit learned in the WoE.
2. **KSC Shortage:** the job requires a KSC, which is not sufficiently supplied as an outcome of any learning unit learned in the WoE.
3. **KSC Surplus:** the learning field provides a KSC, which is more than required by the job.
4. **KSC Obsolete:** the learning field provides a KSC, which is not required by the job anymore.
5. **KSC Balance:** the job requires a KSC, which is sufficiently supplied as an outcome of the learning field.

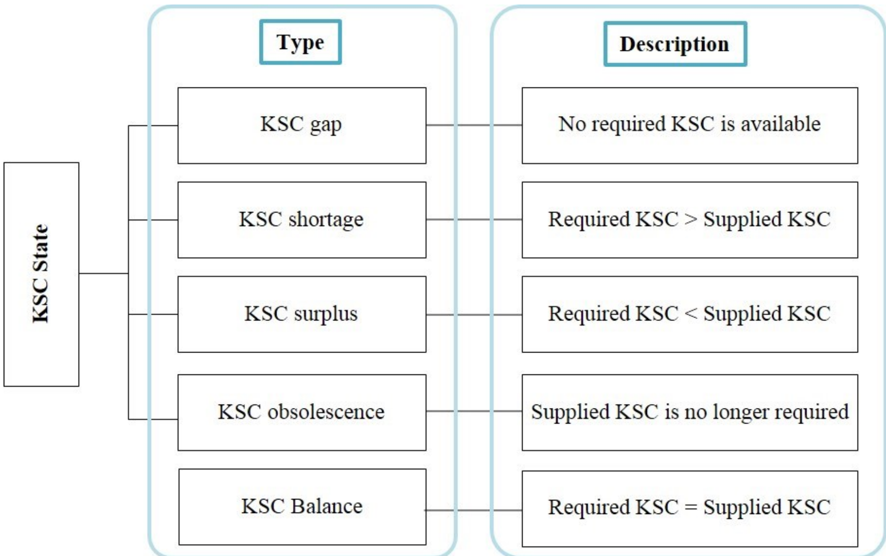


Figure 41 Types and Descriptions of KSC States - Adopted from (Cedefop 2015)

In an evolving knowledge-intensive job market, the WoW (demand side) naturally faces changes with different paces, like the emergence of new technologies and services, with respect to either the push or the pull strategy (i.e. the first one is based on the forecast, while the latter strategy is based on the demands) (Hinkelman 2005). Therefore, the WoW should define new/emerging tasks and/or new jobs. The WoE also faces changes due to new/emerging knowledge and findings in the world of science and technology leading to the definition of new learning units or the revision of the existing ones based on the occurred or anticipated changes. To tackle the imbalance problems, not only the current supplied and demanded KSCs should be matched, but the required "KSCs of future" should be identified in right time and, as a consequence, the appropriate interventions should be applied.

6.3 Domains Alignment

In the present thesis, the term matching is used to find correspondence between the two domains of WoW and WoE, and to match these two domains from KSC nodes to build an ontology called Job-Know Ontology. The term 'alignment' is also used when the author wants to adjust two entities i.e. concept and individual of the domains. While alignment is the discussion on correspondence between entities, matching is the application of connecting the entities. To align and match domains three issues should be identified: i) the alignment approach, ii) alignment level, and iii) alignment time. Each of these issues is described in the following:

Alignment approach - The ontology matching is a challenging activity for both human and machine (Falconer and Noy 2011). The domains, which are matched by machines, should be evaluated by humans, making it a time-consuming task (Falconer and Noy 2011) that may result in undesired logical consequences (Solimando, Jiménez-Ruiz and Guerrini 2016). However, a number of sophisticated ontology matching systems are developed (Shvaiko and Euzenat 2013) that facilitate the matching process. The domain expert should determine whether or not the correspondence (relations) is correctly defined, and if needed, add, delete and/or edit the correspondences. To do so, the experts, who should be involved in the process, should have knowledge of both domains that are under matching activities (Falconer and Noy 2011). When the matching nodes are few, it is not always effective and efficient to use automatic tools (i.e. unsupervised approach) for matching ontologies, and therefore, manual or semi-automatic (supervised or semi-supervised) approaches are sometimes more suitable.

Alignment time – The time that alignment should occur is distinguished between design time and runtime. In the matching design time, the matching operation should be applied before the application can be run, while a runtime operation applies matching during running the application (e.g. search) (Shvaiko and Euzenat 2013). The design time matching can apply manual approaches to match the domains, while the runtime needs to use semi- or automatic approaches.

Alignment level - The alignment can occur either in the element level or in the structure level. The former includes language-based and constraint-based algorithms and the latter includes taxonomy-based and model-based matching algorithms (Mukkala, et al. 2015).

Language-based matching algorithms match the elements fully or partially based on the names or description. Such methods may simply use synonyms (i.e. two words that can be interchanged), hypernyms (i.e. a word that is more generic than a given word), or edit distance (i.e. how many edits are needed to equal the two words) (Mukkala, et al. 2015). Constraint-based matching algorithms are based on data types, the uniqueness of attributes and primary keys. These algorithms narrow down the result but cannot be used alone. Taxonomy-based matching algorithms use taxonomy graphs and find the similarities between the entities by comparing paths of the taxonomy structure (i.e. a child of a parent can be matched). Model-based matching algorithms use the formal semantics relation between the elements (Shvaiko and Euzenat 2013).

To align the WoW and WoE domains via KSC, there is an indispensable need to involve KU and KP (cf. Chapter 3.7), as they provide the correspondence and can correct or optimize the alignments, which are defined incorrectly or inappropriately. Furthermore, the network of experts or crowd (e.g. through using crowd sourcing methods depending on the domain) can also be involved in the process of alignment by collecting their input or feedback.

To proceed with the alignment activity for the Job-Know Ontology, the three issues discussed earlier are elaborated in Table 14.

Table 14 Job-Know Ontology Alignment Activity

Issue	***Issue in Detail***	***Job-Know Ontology Selection***	***Remark***
Alignment Approach	*Manual*	√	*The expert domain needs to analyze the learning outcomes on the one hand and on the other the Job-KSCs to determine whether or not they are equal in quantity and quality. This alignment is not based on the similarities of the terms, despite being based on the mental objective, which carries the terms. In addition, the numbers of the element that should be aligned are not huge, so it is not time-consuming.*
	Semiautomatic	–	
	Automatic	–	
Alignment Time	*Design time*	√	*The alignment between WoW and WoE domains occurs in design time, as changing data does not happen dramatically, and in every running time.*
	Run time	–	
Alignment Level	*Element*	√	*The alignment of WoW and WoE is element-based since the aim is relating the end node of learning outcomes to the Job-KSCs based on the same interpretations of the individuals. This alignment is semantic context-based. Moreover, it is not restricted to the syntax and similarities between the terms and lexicons.*
	Structure	–	

A correspondence between the two domains of WoW and WoE includes four elements: i) *Learning Outcome*, which is the first domain, ii) *Job-KSC*, which is the second domain, iii) *r* represents whether there is any correspondence between the individuals of *Job-KSC* and the individuals of *Learning Outcome. r* can take one of these two types: (≡) when there is a correspondence between the domains, or (—) when there is no correspondence between the domains, and iv) *n* represents how much *r* is strong, *n* is either "high" or "low".

KP determines the correspondences between learning outcomes and Job-KSCs, and also value *n*. Later the *KSC* concept is instantiated based on *r* and *n* values. There are five conditions to define the individuals of *KSC* concept described by Table 15. The first column of the table (**If**) represents the condition, the second column (**And**) completes the condition and the last column (**Then**) defines the action (**A**).

Table 15 Conversion Table- Five conditions, which define correspondence between WoW and WoE Individuals

Action	***If***	***And***	***Then***
A1	*There is correspondence r (≡) between lo_g and $job\text{-}ksc_j$,and n=High*	*there is no correspondence between lo_g/$Job\text{-}KSC_j$ and the other individuals of Job-KSC concept/ Learning Outcome concept*	*instantiate a* ***new*** *individual as ksc_x for KSC concept*
A2	*There is correspondence r (≡) between lo_g and $job\text{-}ksc_j$, and n=Low*	*there is no correspondence between lo_g/$job\text{-}ksc_j$ and the other individuals of Job-KSC concept/ Learning Outcome concept*	*instantiate a* ***new*** *individual as ksc_x for KSC concept*
A3	*There is correspondence r (≡) between lo_g and $job\text{-}ksc_j$, and n=High*	*there is a correspondence r (≡) between lo_g/$job\text{-}ksc_j$ and $job\text{-}ksc_p$/lo_q and n=High*	*reuse the* ***existing*** *ksc_x from the KSC concept and connect it to $job\text{-}ksc_p$/lo_q, which has correspondence with lo_g/$job\text{-}ksc_j$*
A4	*There is correspondence r (≡) between lo_g and $job\text{-}ksc_j$, and n=Low*	*there is a correspondence r (≡) between lo_g/$job\text{-}ksc_h$ and $job\text{-}ksc_p$/lo_q and n=Low*	*reuse the* ***existing*** *individual as ksc_y from the KSC concept and connect it to lo_g/$job\text{-}ksc_j$, which has no correspondence with the individuals of another concept (Job-KSC/Learning Outcome)*
A5	*There is no correspondence (—) between lo_g/ $job\text{-}ksc_j$ and any individual from Job-KSC/Learning Outcome concepts*	—	*instantiate a new individual as ksc_x for the KSC concept and connect it to lo_g/$job\text{-}ksc_h$*

The concept of KSC is defined to host the individuals, which are matched learning outcomes and Job-KSCs (cf. WoC-D1-C).

$$KSC \equiv consistsOf.Knowledge(ksc) \vee consistsOf.Skill(ksc) \vee consistsOf.Competence(kcc)$$

(WoC-D1-C)

Table 16 shows an example to explain how the individuals of the *KSC* concept are instantiated based on value given to *r* and *n*. For instance, the Action (**A1**-Table 15) occurs when, lo_1 and *job-ksc*$_3$ has r (≡) and *n=High* (**If** column-Table 15), and there is no correspondence between lo_1/*job-ksc*$_3$ and the other individuals of *Job-KSC* concept/ Learning *Outcome* concept (**And** column-Table 15), then there is a need to instantiate a **new** individual as ksc_1 for *KSC* concept (**Then** column-Table 15).

Table 16 An Example - Alignment between Learning outcomes and KSC - determine Correspondence and instantiate KSC Concept

Learning Outcome	***Job-KSC***	***If***		***And***		***Then Action (A)***	
		r	***n***	***r***	***n***		
WoE: lo$_1$	***WoW: job-ksc$_2$***	≡	*High*	–	–	*A1*	*Instantiate a new **ksc$_1$** for KSC concept in connection with lo$_1$ and job-ksc$_2$*
WoE: lo$_2$	***WoW: job-ksc$_3$***	≡	*Low*	–	–	*A2*	*Instantiate a new **ksc$_2$** for KSC concept in connection with lo$_2$ and job-ksc$_3$*
WoE: lo$_3$	***WoW: job-ksc$_3$***	≡	*High*	≡ *job-ksc$_3$, job-ksc$_2$*	*High*	*A3*	*Reuse **ksc$_1$** for KSC concept in connection with lo$_3$ and job-ksc$_2$*
WoE: lo$_4$	***WoW: job-ksc$_4$***	≡	*Low*	≡ *lo$_4$, lo$_5$*	*Low*	*A4*	*Reuse **ksc$_3$** for KSC concept in connection with lo$_4$ and job-ksc$_4$*
WoE: lo$_5$	***WoW: job-ksc$_5$***	–	–	–	–	*A5*	*Instantiate a new **ksc$_3$** for KSC concept in connection with lo$_5$* *Instantiate a new **ksc$_4$** for KSC concept in connection with job-ksc$_5$*

6.4 3-D Space of Task, KSC and Learning Unit

The two dimensions of tasks of a job are identified based on the job description (vertical axis of tasks) and required Job-KSCs extracted from the job specification (horizontal axis Job-KSCs) that build up the demand space depicted by Figure 42.

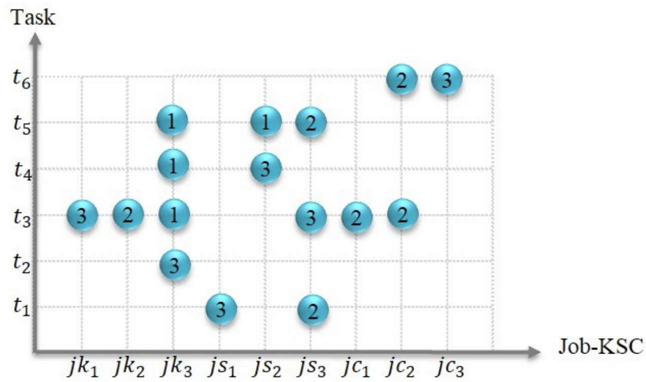


Figure 42 An-Example: Demand Space, the blue circles reflect the DDs of the tasks and the Job-KSCs

The blue circles in the demand space represents the *DDs* of the tasks to Job-KSCs specified by the sub-roles of *requires()* (WoW-R5) (cf. Chapter 4.5.3). The demand space is actually the visualization of the *TC* matrix (cf. Chapter 4.4). For example, to be able to perform task t_1, Job-KSC js_1 and Job-KSC js_3 with *DDs* of 3 and 2 are required, respectively. Notably, the lower bound of *DD* is 0 and the upper bound is 3 (cf. Chapter 4.3.2).

The two dimensions of learning units of a learning field refer to a specific curriculum (vertical axis of learning unit), and learning outcomes (horizontal axis of learning outcome), which build up the supply space. Figure 43, as an example, the orange circles in the supply space represent the SDs of the learning units and learning outcomes specified by the sub-roles of *qualifiesToObtain()* (WoE-R3). The supply space is, in fact, the visualization of the *LuLo* matrix (cf. Chapter 5.5.2). For example, to obtain learning outcome lo_4, learning unit lu_1 and lu_2, respectively, with the *SDs* of 2 and 1 should be learned. Similarly, the lower bound of *SD* is 0 and the upper bound is 3 (cf. Chapter 5.3.2).

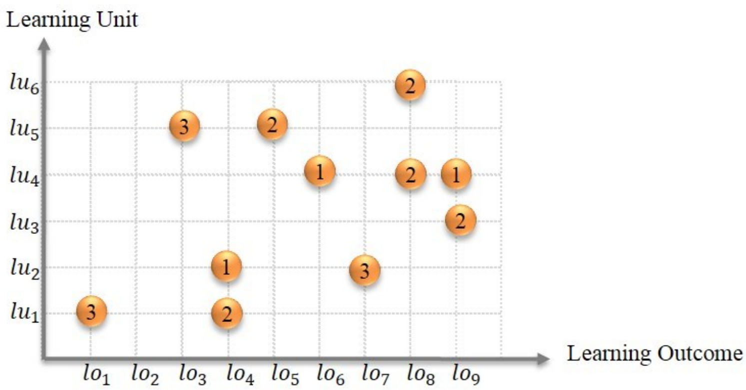


Figure 43 An-Example: Supply Space, the orange circles reflects the SDs of learning units and learning outcomes

The conjunction of the two spaces of demand and supply leads to build the matching space based on the Task and Learning Unit axes. The matching space represents the matching states of the tasks and the learning units via KSCs. Ultimately, the 3-D space of Task-KSC-Learning unit (TkscL), which includes demand, supply, and the matching spaces are shaped (cf. Figure 44).

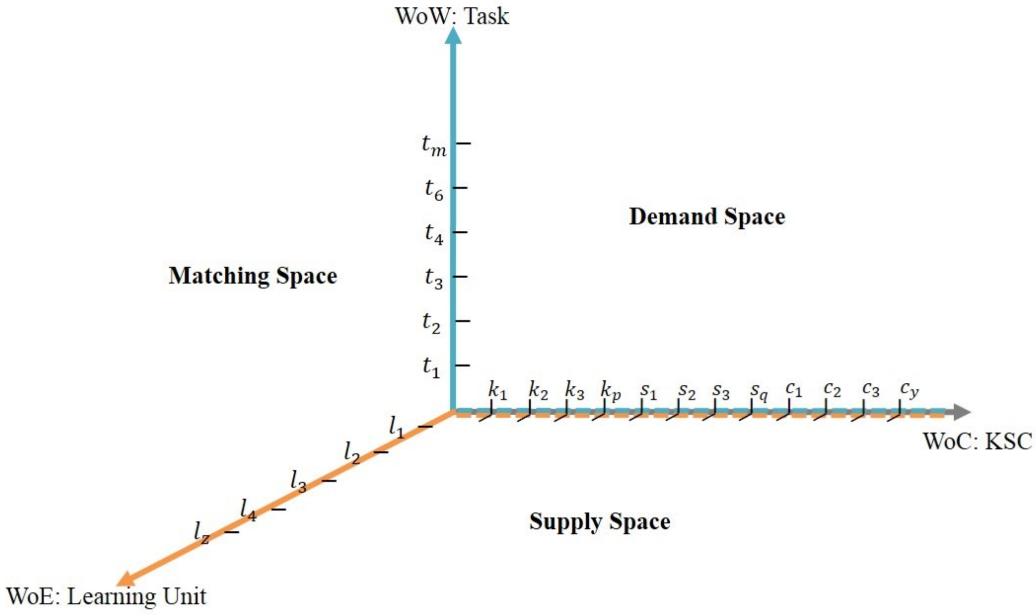


Figure 44 Demand, Supply and Matching Spaces and ultimately 3-D Space of TkscL

In the following relation (1) and (2) are defined based on the roles of *requires()* (cf. WoW-R5) and *qualifiesToObtain()* (cf. WoE-R3), respectively. Then relation (3) is inferred when the 3-D space of TkscL is built up (cf. WoC-R1) (Khobreh, Ansari and Fathi, et al. 2016).

(1)Demand Space: To perform Task *t*

- Knowledge *k*, Skill *s* and/or Competence *c* is required with the respected *DD* (cf. Figure 42).

(2)Supply Space: Learning Unit *l* qualifies to obtain

- Knowledge *k*, Skill *s* and/or Competence *c* with the respected *SD* (cf. Figure 43).

(3)Matching Space: Learning Unit *l* is a qualified enabler for Task *t* with the respected matching state of supply and demand (cf. Chapter 6.2).

$$\exists t, ksc, lu$$
$$isQualifiedEnablerFor(lu, t) \subset Task(t) \wedge KSC(ksc) \wedge LearningUnit(lu) \wedge requires(t, ksc) \wedge qualifiesToObtain(lu, ksc)$$

(WoC-R1)

The variable *MS* is value based on inferring the relation between "Task and KSC" and consequently, "KSC and Learning Unit" to identify the matching states of "Task and Learning Unit". In this way, the five matching states, namely, Gap (G), Shortage (S), Surplus (U), Obsolence (O), and Balance (B) are inferred in the matching space (cf. Figure 45).

Figures 45 follows the examples visualized by Figure 42 and 43 and represents the 3-D space of TkscL. For instance, performing Task t_3 requires Knowledge k_1 with *DD* of 3, k_2 with *DD* of 2, k_3 with *DD* of 1 and Competence c_1 with *DD* of 2 and Competence c_2 with *DD* of 3. To obtain the aforementioned KSCs required to perform Tasks t_3, learners should practice the Learning Units lu_1 with *SD* of 3 to be qualified in Knowledge k_1, Learning Units lu_5 with *SD* of 3 to be qualified in Knowledge k_3, Learning Units lu_2 with *SD* of 3 to be qualified in Competence c_1, and Learning Units lu_4 and lu_6 with *SD* of 2 to be qualified in Competence c_2. Ultimately, it is inferred that the Learning Unit lu_1 is a qualified enabler for Task t_3 in Balance state, the Learning Units lu_2 and lu_5 is a qualified enabler for Task t_3 in Surplus state, and the Learning Units lu_4 and lu_6 is a qualified enabler for Task t_3 in Shortage state.

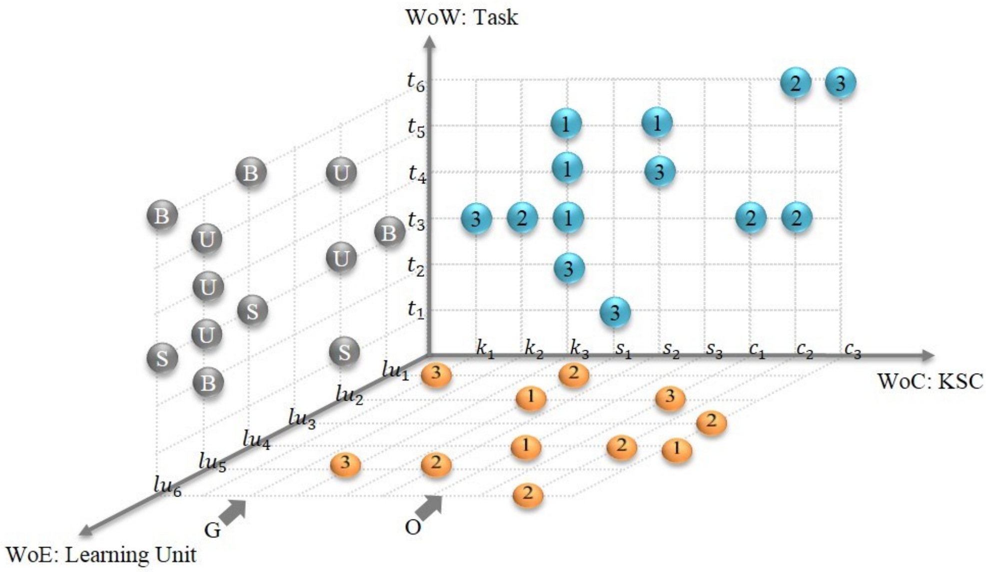


Figure 45 An Example to visualize 3-D Space of TkscL, the gray circles are inferred the matching states from the relations between Task, KSC and Learning Unit

The super-role of $isQualifiedEnablerFor()$ is subdivided into five sub-roles to infer each matching state. In the following, the sub-roles are described in detail.

Gap state (G) – (cf. WoC-R2)**:** there is no learning unit which qualifies learners to obtain the KSC(s) required. However, this KSC is (these KSCs are) needed by a task (i.e. imbalance problem).

- Condition: $(DD \neq 0 \text{ } and \text{ } SD = 0) \rightarrow SM = Gap$

- Example: According to the example illustrated in Figure 45, Task t_3 requires set of KSCs, such as Knowledge k_2. To obtain this KSC, however, no Learning Unit is specified. It is inferred that by learning the learning units of this curriculum, learners cannot obtain the required KSC to perform the selected task. This reflects the gap of KSC in supply.

$$\exists t_i, ksc_j, \forall lu$$
$$isQualifiedEnablerFor-Gap(lu,t) \subset Task(t) \wedge LearningUnit(lu) \wedge KSC(ksc) \wedge \big(requires-Strongly(t,ksc) \vee requires-Moderately(t,ksc) \vee requires-Weakly(t,ksc)\big) \wedge qualifiesToObtain-Not(lu,ksc)$$

(WoC-R2)

Shortage state (S) – (cf. WoC-R3)**:** a learning unit qualifies learners to obtain a KSC(s) less than required by WoW. Therefore, there is a lack of KSC to perform the identified task(s).

- Condition: $(DD \neq 0 \; and \; SD \neq 0 \; and \; DD > SD) \rightarrow SM = Shortage$
- Example: According to the example illustrated in Figure 45, Task t_6 requires Competence c_3 with *DD* of 3, while to obtain Competence c_3, Learning Unit lu_2 with *SD* of 2 is required. Notably, here the *MaxLoObtainsFLu* Matrix (WoE-M5) is used to identify the maximum value of *SD*. In this case, the level of required competence is not in balance with the supplied competence. Thus, there is a shortage, which means by acquiring the learning units of this curriculum, learners cannot obtain the sufficient learning outcome to perform the task competently.

$$\exists t, ksc, \forall lu$$
$$isQualifiedEnablerFor-Shortage(lu,t) \subset Task(t) \wedge Learningunit(lu) \wedge KSC(ksc) \wedge \Big(\Big(\big(requires-Strongly\ (t,ksc) \vee requires-Moderately(t,ksc\ )\big) \wedge qualifiesToObtain-Weakly(t,ksc)\Big) \vee \Big(requires-Strongly\ (t,ksc) \wedge \big(qualifiesToObtain-Moderately(lu,ksc) \vee qualifiesToObtain-Weakly(lu,ksc)\big)\Big)\Big)$$

(WoC-R3)

Surplus state (U) – (cf. WoC-R4)**:** a learning unit qualifies learners to obtain a KSC(s) more than required for the job. Therefore, there is extra KSCs provided in terms of quality and/or quantity.

- Condition: $(DD \neq 0 \; and \; SD \neq 0 \; and \; DD < SD) \rightarrow SM = Surplus$
- Example: According to the example illustrated in Figure 45, Task t_3 requires (moderately) Competence c_1. To obtain this KSC, Learning Unit lu_2 is strongly required. In

this case, the level of supplied competence is more than the demand; therefore, there is a surplus.

$$\exists t, ksc, \forall lu$$
$$isQualifiedEnablerFor - Surplus(lu, t) \subset Task(t) \wedge Learningunit(lu) \wedge KSC(ksc) \wedge \Big(\big(requires - Weakly\ (t, ksc) \wedge \big(qualifiesToObtain - Moderately(lu, ksc) \vee qualifiesToObtain - Strongly(lu, ksc)\big)\big) \vee \big(requires - Moderately\ (t, ksc) \wedge requiresToObtain - Strongly(lu, ksc)\big)\Big)$$

(WoC-R4)

Obsolete state (O) – (cf. WoC-R5)**:** a learning unit qualifies learners to obtain a KSC(s), which is not needed (at all or any more) to perform the tasks of this job.

- Condition: $(DD = 0\ and\ SD \neq 0) \rightarrow SM = Obsolete$
- Example: According to the example illustrated in Figure 45, Learning Unit lu_1 qualifies learners to obtain Skill s_3, with *SD* of 1. However, there is No task, which requires this skill. In this case, the supplied skill is not required anymore; therefore, there it is obsolete.

$$\exists ksc\ \forall lu, t$$
$$isQualifiedEnablerFor - Obsolete(lu, t) \subset Task(t) \wedge Learningunit(lu) \wedge KSC(ksc) \wedge \big(requires - Not(t, ksc\ ) \wedge \big(qualifiesToObtain - Strongly(lu, ksc) \vee qualifiesToObtain - Moderately(lu, ksc) \vee qualifiesToObtain - Weakly(lu, ksc)\big)\big)$$

(WoC-R5)

Balance state (B) – (cf. WoC-R6)**:** a learning unit qualifies learners to obtain required KSCs sufficiently and have the potential to perform the assigned task competently.

- Condition: $(DD = SD\ and\ SD \neq 0\ and\ DD \neq 0) \rightarrow SM = Balance$
- Example: According to the example illustrated in Figure 45, Task t_3 requires Knowledge k_1 with *DD* of 3, and Learning Unit lu_1 qualifies learners to obtain Knowledge k_1, with *SD* of 3. In this case, knowledge supplied and required by learning unit and task, respectively, is in balance.

$$\exists t, ksc\ \forall lu$$
$$isQualifiedEnablerFor - Balance(lu, t) \equiv Task(t) \wedge Learningunit(lu) \wedge KSC(ksc) \wedge \big(\big(requires - Weakly\ (t, ksc) \wedge qualifiesToObtain - Weakly(lu, ksc)\big) \vee \big(requires -$$

$$Moderately\ (t, ksc) \wedge qualifiesToObtain - Moderately\ (lu, ksc)\big) \vee \big(requires - Strongly\ (t, ksc) \wedge qualifiesToObtain - Strongly(lu, ksc)\big)\Big)$$

(WoC-R6)

6.5 Analysis of Matching Space

The Matching space (i.e. a conjunction of Task and Learning Unit axes) provides the opportunity to analyze the matching states with two perspectives: Learning Unit-oriented and Task-oriented (c.f. Figure 46). The first orientation answers the question of how much a learning unit qualifies learners to correctly obtain KSCs demanded by the job. While the latter orientation is to provide the answer to the question of how much a task is competently performed by learning the given learning units of the curriculum.

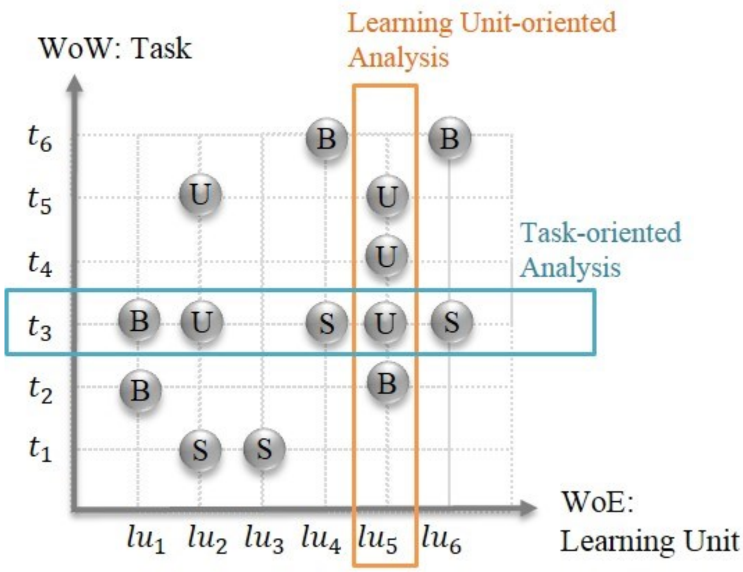


Figure 46 Analysis of Matching Space

The learning Unit-Oriented analysis identifies four cases as described below.

Case I - (cf. WoC-R7): the learning unit that qualifies learners to obtain the KSCs required by this job, is in Balance. For instance, learning unit lu_1 sufficiently qualifies learners to obtain KSCs required by this job (cf. Figure 46).

$$\exists lu, \forall t$$
$$MS4LU - inBalance(lu) \subset isQualifiedEnablerFor - Not(lu, t_i) \bigvee_{i \in index\ of\ Tasks} isQualifiedEnablerFor - Balance(lu, t_i)$$

(WoC-R7)

However, the combinations of imbalanced matching states are identified in the next three cases:

Case II- (cf. WoC-R8): the learning unit qualifies learners to obtain KSCs required by some tasks with Gap/Shortage, however, for some tasks it is in Balance. For instance, *lu₄* qualifying learners to obtain KSCs required by this job is in Shortage (cf. Figure 46).

$$\exists lu, \forall t$$
$$MS4LU - inShortageBalance(lu) \subset \bigvee_{a \in index\ of\ Tasks,\ a \neq i} isQualifiedEnablerFor - Gap(lu, t_a) \bigvee_{b \in index\ of\ Tasks,\ b \neq i} isQualifiedEnablerFor - Shortage(lu, t_b) \bigvee_{i \in index\ of\ Tasks,\ i \neq a,\ i \neq b} isQualifiedEnablerFor - Balance(lu, t_i)$$

(WoC-R8)

Case III- (cf. WoC-R9): the learning unit qualifies learners to obtain KSCs required by some tasks with Surplus. For instance, lu_5 qualifying learners to obtain KSCs required by this job is in Surplus (cf. Figure 46).

$$\exists lu, \forall t$$
$$MS4LU - inSurplusBalance(lu) \subset \bigvee_{a \in index\ of\ Tasks,\ a \neq i} isQualifiedEnablerFor - Surplus(lu, t_a) \bigvee_{i \in index\ of\ Tasks,\ i \neq a} isQualifiedEnablerFor - Balance(lu, t_i)$$

(WoC-R9)

Case IV- (cf. WoC-R10): the learning unit qualifies learners to obtain KSCs required by some tasks with Gap/Shortage, but the other with Surplus. For instance, lu_2 qualifying learners to obtain KSCs required by this job in shortage for some tasks and in Surplus for the others (cf. Figure 46).

$$\exists lu, \forall t$$
$$MS4LU - inMixed(lu) \subset MS4LU - inShortageBalance(lu) \wedge MS4LU - inSurplusBalance(lu)$$

(WoC-R10)

In case I, there is no need to revise the learning unit to perform the tasks as described in the current time. However, case II, III and IV need revision either in the learning units or in the tasks of the job. With respect to case II, the learning unit should be modified in a way to compensate for the Gap and Shortage, i.e. improving and/or increasing the content (i.e. quality and level of details and/or adding new content) to supply the requirements. For case III, the learning unit provides more KSCs than required. Therefore, the content should be decreased or the level of details should be adjusted. While case IV shows Balance in the requirement level of tasks, the learning units satisfy some tasks but not all. Thus, the tasks should be first analyzed and then modified in a way that the KSCs required are at the same level, in terms of quality and level of details.

Furthermore, the second question which should be analyzed refers to each task of the job. The task-oriented analysis identifies four cases as described below:

Case I - (cf. WoC-R11): all of the KSCs required to perform a task are in Balance. Therefore, there is the potential for this task to be performed competently. For instance, KSCs required to perform task t_6 are supplied is in Balance (cf. Figure 46).

$$\exists t, \forall lu$$
$$MS4T - inBalance(t) \subset isQualifiedEnablerFor - Not(lu_h, t) \bigvee_{h \in index\ of\ Learning\ Units} isQualifiedEnablerFor - Balance(lu_h, t)$$

(WoC-R11)

However, the combination of imbalanced matching states determines the next three cases:

Case II- (cf. WoC-R12): all/some KSCs required to perform a task are in Gap/Shortage. Therefore, potentially this task cannot be performed competently. KSCs required to perform task t_1 are supplied in Shortage (cf. Figure 46).

$$\exists t, \forall lu$$
$$MS4T - inShortageBalance(t) \subset \bigvee_{m \in index\ of\ Tasks,\ m \neq h} isQualifiedEnablerFor - Gap(lu_h, t) \bigvee_{n \in index\ of\ Learning\ Units,\ n \neq h} isQualifiedEnablerFor - Shortage(lu_h, t) \bigvee_{h \in index\ of\ Learning\ Units,\ h \neq m,\ h \neq n} isQualifiedEnablerFor - Balance(lu_h, t)$$

(WoC-R12)

Case III- (cf. WoC-R13): all/some KSCs required to perform a task are in Surplus. Therefore, potentially this task is boring for overqualified employees. For instance, KSC required to perform task t_5 are supplied in Surplus (cf. Figure 46).

$$\exists t, \forall lu$$
$$MS4T - inSurplusBalance(t) \subset \bigvee_{m \in index\ of\ Tasks,\ m \neq h} isQualifiedEnablerFor - Surplus(lu_h, t) \bigvee_{h \in index\ of\ Learning\ Units,\ h \neq m} isQualifiedEnablerFor - Balance(lu_h, t)$$

(WoC-R13)

Case IV- (cf. WoC-R14): some KSCs required to perform a task are in a mix of Gap/Shortage and/or Surplus. Therefore, potentially this task cannot be performed competently. For instance, some KSCs required to perform task t_3 are supplied in Shortage, some in Surplus, and others in Balance (cf. Figure 46).

$$\exists t, \forall lu$$
$$MS4T - inMixed(t) \subset MS4T - inShortageBalance(t) \wedge MS4T - inSurplusBalance(t)$$

(WoC-R14)

In case I, there is no need to revise the learning unit or task to achieve Balance in the current time. However, case II, III and IV need revision either in the learning units or in the tasks of the job. With respect to case II, the task should be revised in a way to compensate for the Gap and Shortage, i.e. decreasing the level of KSCs required to meet the supply. For case III, the task should be revisited seeking ways to increase the level of KSCs required to perform it. While case IV shows Balance in level, as the task requires, although the learning units satisfy some tasks but not all. Thus, the tasks should be first analyzed and then revised so that the KSCs required are at the same level in terms of quality and levels of details. Therefore, depending on the detected shortage either the task should be revised or the learning units.

6.6 Supplied and Demanded KSC Over time

In an evolving and dynamic job market, demand for KSCs is not static due to the appearance of new and/or emerging tasks and ultimately jobs. Moreover, to increase productivity and tackle the employment and job market development problems, there is a need to sustain required KSCs to perform the demands of the WoW over time (Cedefop, ILO 2015). Alternatively, by referring to the new/emerging findings in science and technology, the learning units should be revised and consequently, their outcomes renewed. Changes in demand/supply should affect the supply/demand to keep the balance between the supply-demand in WoC. To establish the communication channel between WoW and WoE, therefore, a time factor should be added to the Job-Know Ontology.

Figure 47 illustrates the KSC radar in which there are three-time instances that KSCs demanded and supplied should be determined: i) current (now), ii) coming soon (short- and/or mid-term), and iii) future (long-term). Current time shows the matching state of KSCs at this moment, i.e. the level of KSCs demanded by the WoW is in balance with those supplied by the WoE (KSCs possessed by learners). In addition, it identifies the level of the learning outcomes provided in past (a time before current), that currently meet the requirements of the WoW. It implies that the WoE should be at least one-time instance ahead of the WoW requirements to be able to achieve balance of supply-demand in the WoC. In this way, the learning outcomes of today should satisfy the coming soon and ultimately future demands of the WoW. Similarly, the learning outcomes of coming soon should meet the future demands of the WoW.

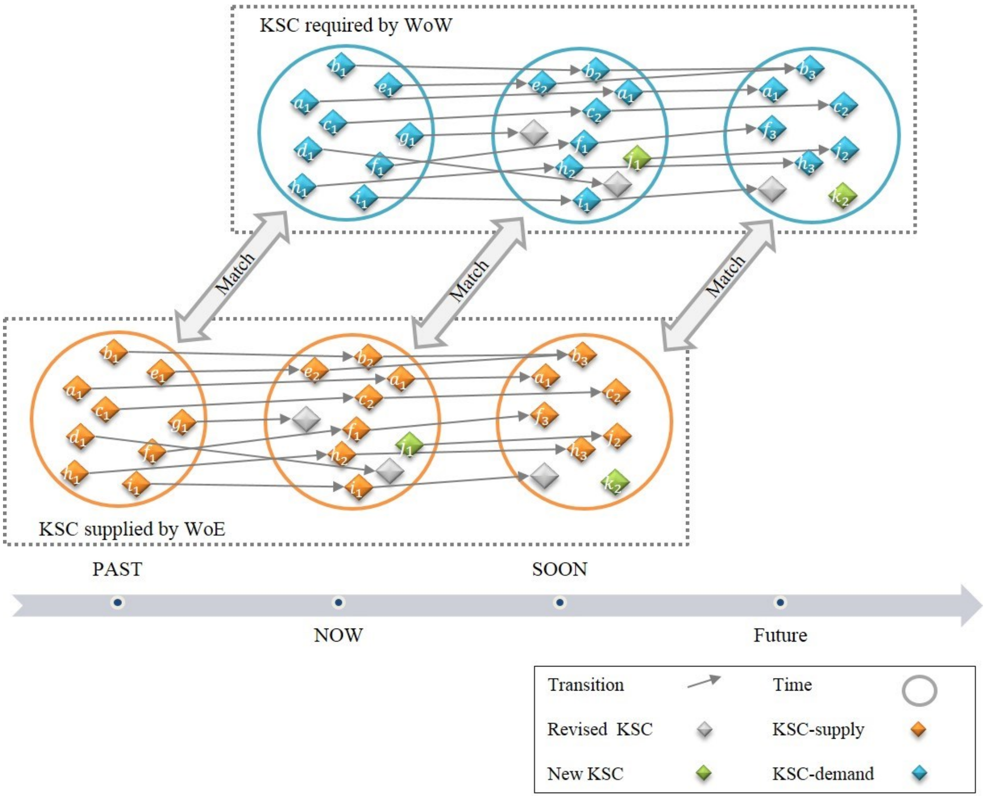


Figure 47 KSC Radar - KSCs demanded by WoW and KSCs supplied by WoE in three times of Now, Soon and Future

Each matching state in current time (t_1) has five ways to transit to another matching state in the next time (t_2). In general, the 25 potential ways may occur based on the multiplication of the numbers of the match states (i.e. five states), to the number of ways leaving a former state or arriving at a new state (i.e. five ways). However, only five ways (blue lines – Figure

48) may lead to the Balance state (B) out of the 25 possible transitions. This is illustrated in Figure 48.

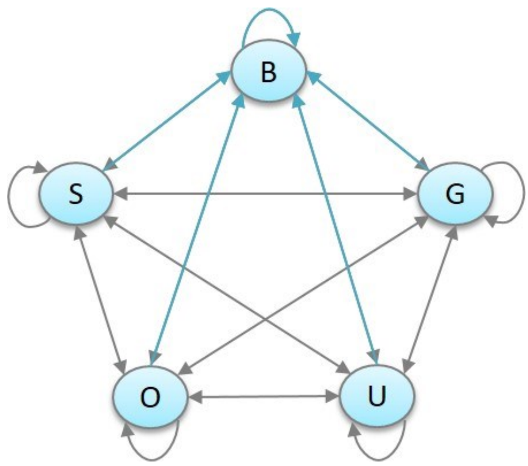


Figure 48 Transition Ways of Matching States from t_1 to t_2 -Balance (B), Gap (G), Shortage (S), Surplus (U) and Obsolete (O)

6.6.1 Transition of Matching States

As discussed earlier, the supply and demand matching process results in one of the five aforementioned states, i.e. Balance, Gap, Shortage, Surplus, and Obsolete. Figure 49 presents the KSC demanded axis (horizontal axis) and KSC supplied axis (vertical axis).

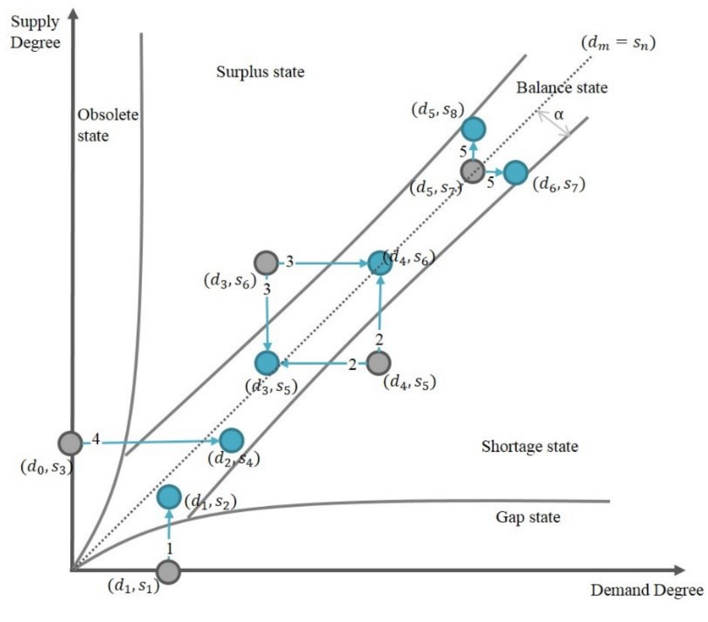


Figure 49: KSC demanded axis (horizontal) and KSC supplied axis (vertical) - The gray circles demonstrate the matching states of a KSC in time t_1 and the blue circles show the (new) states time t_2 after the transition

The gray circles visualize the matching states of the current time t_1 based on the value given to the KSC demanded as *DD* and the KSC supplied as *SD*. The coming soon/future time t_2 is in blue. In this thesis, coming soon and future time instances are considered the same, as the short, mid and long term does not change the conditions described later. Notably, the curves, which demonstrate the areas of the matching states, are just drawn for the sake of visualizing of the concept, therefore, they are not used to reflect any mathematical meaning.

To sustain and balance the KSC matching state, three specific interventions can be applied by the WoW and/or WoE as mentioned by Table 17.

Table 17 Actions to transit/stay in Balance state

Action	***Actor***	***Description***
A	*WoW*	*Revise the task to decrease/increase the demand for KSC and ultimately to balance supply-demand.*
B	*WoE*	*Revise the learning unit to decrease/increase the supply of KSC and ultimately to balance supply-demand.*
C	*WoW & WoE*	*Revise the task to decrease/increase the demand for KSC and revise the learning unit to increase/ decrease the supply of KSC, which ultimately lead to balance supply-demand.*

Applying the actions mentioned in Table 17, six functional roles for the WoW and WoE are defined. To increase, decrease or keep the *DD* value of a task and KSC in a time, the following roles are defined; *move-forward-WoW()* (WoW-R6), *move-Backward-WoW()* (WoW-R7) and *move-Not-WoW()* (WoW-R8). To increase, decrease or keep the *SD* value of a learning unit and KSC in a time, the roles of *move-forward-WoE()* (WoE-R4), *move-Backward-WoE()* (WoE-R5) and *move-Not-WoE()* (WoE-R6) are defined.

$$move-Forward-WoW(t,ksc) \subset Task(t) \wedge KSC(ksc) \wedge \Big(\big((requires-Not(t,ksc) \wedge time(ti_1)) \wedge ((requires-Weakly(t,ksc) \vee requires-Moderately(t,ksc) \vee requires-Strongly(t,ksc)) \wedge time(ti_2))\big) \vee \big((requires-Weakly(t,ksc) \wedge time(ti_1)) \wedge ((requires-Moderately(t,ksc) \vee requires-Strongly(t,ksc)) \wedge time(ti_2))\big) \vee \big((requires-Moderately(t,ksc) \wedge time(ti_1)) \wedge (requires-Strongly(t,ksc) \wedge time(ti_2))\big)\Big)$$

(WoW-R6)

$$move-Backward-WoW(t,ksc) \subset Task(t) \wedge KSC(ksc) \wedge \Big(\big((requires-Weakly(t,ksc) \wedge time(ti_1)) \wedge (requires-Not(t,ksc) \wedge time(ti_2))\big) \vee \big((requires-Moderately(t,ksc) \wedge time(ti_1)) \wedge ((requires-Not(lu,ksc) \vee requires-Weakly(t,ksc)) \wedge time(ti_2))\big) \vee \big((requires-Strongly(t,ksc) \wedge time(ti_1)) \wedge ((requires-Weakly(t,ksc) \vee requires-Moderately(t,ksc)) \wedge time(ti_2))\big)\Big)$$

(WoW-R7)

$$move-Not-WoW(t,ksc) \subset Task(t) \wedge KSC(ksc) \wedge \Big(\big((requires-Not(t,ksc) \wedge time(ti_1)) \wedge (requires-Not(t,ksc) \wedge time(ti_2))\big) \vee \big((requires-Weakly(t,ksc) \wedge time(ti_1)) \wedge (requires-Weakly(t,ksc) \wedge time(ti_2))\big) \vee \big((requires-Moderately(t,ksc) \wedge time(ti_1)) \wedge (requires-Moderately(t,ksc) \wedge time(ti_2))\big) \vee \big((requires-Strongly(t,ksc) \wedge time(ti_1)) \wedge (requires-Strongly(t,ksc) \wedge time(ti_2))\big)\Big)$$

(WoW-R8)

$$move-Forward-WoE(lu,ksc) \subset LearningUnit(lu) \wedge KSC(ksc) \wedge \Big(\big((qualifiesToObtain-Not(lu,ksc) \wedge time(ti_1)) \wedge ((qualifiesToObtain-Weakly(lu,ksc) \vee qualifiesToObtain-Moderately(lu,ksc) \vee qualifiesToObtain-Strongly(lu,ksc)) \wedge time(ti_2))\big) \vee \big((qualifiesToObtain-Weakly(lu,ksc) \wedge time(ti_1)) \wedge ((qualifiesToObtain-Moderately(lu,ksc) \vee qualifiesToObtain-Strongly(lu,ksc)) \wedge time(ti_2))\big) \vee \big((qualifiesToObtain-Moderately(lu,ksc) \wedge time(ti_1)) \wedge (qualifiesToObtain-Strongly(lu,ksc) \wedge time(ti_2))\big)\Big)$$

(WoE-R4)

$$move-Backward-WoE(lu,ksc) \subset LearningUnit(lu) \wedge KSC(ksc) \wedge \Big(\big((qualifiesToObtain-Weakly(lu,ksc) \wedge time(ti_1)) \wedge (qualifiesToObtain-Not(lu,ksc) \wedge time(ti_2))\big) \vee \big((qualifiesToObtain-Moderately(lu,ksc) \wedge time(ti_1)) \wedge ((qualifiesToObtain-Not(lu,ksc) \vee qualifiesToObtain-Weakly(lu,ksc)) \wedge time(ti_2))\big) \vee \big((qualifiesToObtain-Strongly(lu,ksc) \wedge time(ti_1)) \wedge ((qualifiesToObtain-Weakly(lu,ksc) \vee qualifiesToObtain-Moderately(lu,ksc)) \wedge time(ti_2))\big)\Big)$$

(WoE-R5)

$$move-Not-WoE(t,ksc) \subset LearningUnit(lu) \wedge KSC(ksc) \wedge \Big(\big((qualifiesToObtain-Not(lu,ksc) \wedge time(ti_1)) \wedge (qualifiesToObtain-Not(lu,ksc) \wedge time(ti_2))\big) \vee \big((qualifiesToObtain-Weakly(lu,ksc) \wedge time(ti_1)) \wedge (qualifiesToObtain-Weakly(lu,ksc) \wedge time(ti_2))\big) \vee \big((qualifiesToObtain-Moderately(lu,ksc) \wedge time(ti_1)) \wedge (qualifiesToObtain-Moderately(lu,ksc) \wedge time(ti_2))\big) \vee \big((qualifiesToObtain-Strongly(lu,ksc) \wedge time(ti_1)) \wedge (qualifiesToObtain-Strongly(lu,ksc) \wedge time(ti_2))\big)\Big)$$

(WoE-R6)

The five possible ways to transit to or stay in the Balance state are discussed below. The variables used to describe each transition are based on the example given in Figure 4, with A, B and/or C letters showing which action(s) should be taken to balance the state (cf. Table 17).

1. Stay in **Balance** state:

   - if $d_5 \approx s_7$ and in the grey point (d_5, s_7);

     a) Then $d_6 = d_5 + x$ and s_7 is fixed, the gray circle of (d_5, s_7) transits to blue circle of$(d_6\,, s_7)$ (cf. Figure 49).

     b) Or $s_7 = s_8 + y$ and d_5 is fixed, the gray circle of (d_5, s_7) transits to blue point of $(d_5\,, s_8)$ (cf. Figure 49).

     c) Or $d_m = d_5 + x$ and $s_n = s_7 + y$, where $d_m \pm \alpha = s_n \pm \alpha$, the gray circle of (d_5, s_7) transits to blue circle of $(d_m\,, s_n)$ (cf. Figure 50).

$$transitsB2B(t, lu) \subset (ti_1 < ti_2) \wedge \big(Time(ti_1) \wedge Task(t) \wedge KSC(ksc) \wedge learningunit(lu) \wedge isQualifiedEnablerFor - Balance(lu, t)\big) \wedge \Big(\Big(\big(move - Forward - WoE(lu, ksc) \wedge move - Forward - WoW(t, ksc)\big) \vee \big(move - Backward - WoE(lu, ksc) \wedge move - Backward - WoW(t, ksc)\big) \vee \big(move - Not - WoE(lu, ksc) \wedge move - Not - WoW(t, ksc)\big)\Big) \wedge \big(isQualifiedEnablerFor - Balance(lu, t) \wedge Time(ti_2)\big)\Big)$$

(WoC-R15)

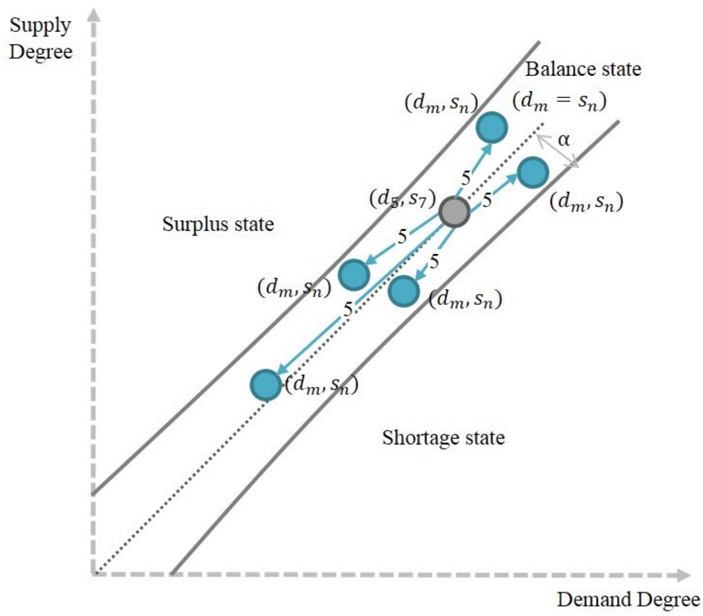


Figure 50 An Example - Transition from Balance state to Balance state

2. Transition from **Gap** state to Balance state:

   - if $s_1 = 0$ and $d_1 \neq 0$, gray circle of (d_1, s_1) in Time t_1;

     a) Then $s_2 = s_1 + y$; the gray circle of (d_1, s_1) transits to blue circle $(d_1\,, s_2)$ in Time t_2 via Action A, (cf. Figure 49).

b) Not applied

c) Or $d_m = d_4 + x$ and $s_n = s_5 + y$, where $d_m \pm \alpha \approx s_n \pm \alpha$, the gray circle (d_0, s_3) transits to blue circle (d_m, s_n) via Action C (cf. Figure 51).

$$transitsG2B(t, lu) \subset (ti_1 < ti_2) \wedge \big(Time(ti_1) \wedge Task(t) \wedge KSC(ksc) \wedge learningunit(lu) \wedge isQualifiedEnablerFor-Gap(lu,t)\big) \wedge \Big(\Big(\big(move-Forward-WoE(lu,ksc) \wedge move-Not-WoW(t,ksc)\big) \vee \big(move-Not-WoE(lu,ksc) \wedge move-Backward-WoW(t,ksc)\big)\Big) \wedge \big(isQualifiedEnablerFor-Balance(lu,t) \wedge Time(ti_2)\big)\Big)$$

(WoC-R16)

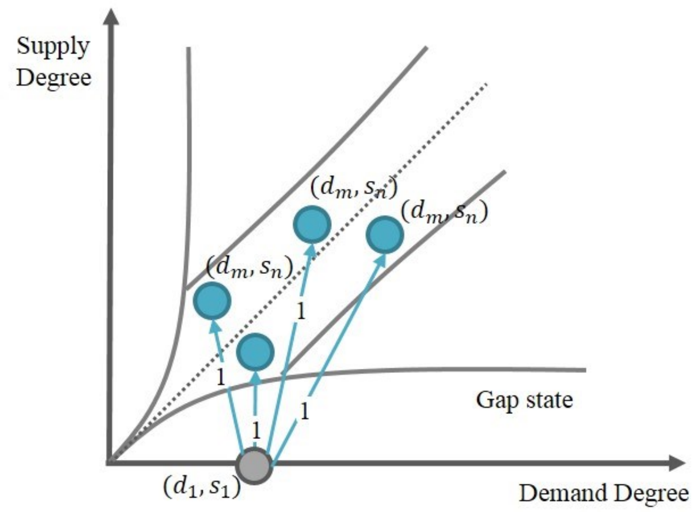


Figure 51 An Example - Transition from Gap state to Balance state

3. Transition from **Shortage** state to Balance state:

- if $s_5 < d_4$ in the gray circle of (d_4, s_5);

a) Then $d_3 = d_4 - x$ and s_5 is fixed the gray circle of (d_4, s_5) transits to blue circle of (d_3, s_5) (cf. Figure 49)

b) Or $s_6 = s_5 + y$ and $d_4$is fixed, the gray circle (d_4, s_5) transits to blue circle (d_4, s_6) (cf. Figure 49).

c) Or $d_m = d_4 + x$ and $s_n = s_5 + y$, where $d_m \pm \alpha = s_n \pm \alpha$, the grey point (d_4, s_5) transits to blue circle (d_m, s_n) (cf. Figure 52).

$$transitsS2B(t, lu) \subset (ti_1 < ti_2) \wedge \big(Time(ti_1) \wedge Task(t) \wedge KSC(ksc) \wedge learningunit(lu) \wedge isQualifiedEnablerFor-Shortage(lu,t)\big) \wedge \Big(\Big(\big(move-Not-WoE(lu,ksc) \wedge move-Backward-WoW(t,ksc)\big) \vee \big(move-Forward-WoE(lu,ksc) \wedge move-Not-WoW(t,ksc)\big) \vee \big(move-Forward-WoE(lu,ksc) \wedge move-Forward-WoW(t,ksc)\big) \vee$$

$$\big(move - Forward - WoE(lu, ksc) \wedge move - Backward - WoW(t, ksc)\big)\big) \wedge \big(isQualifiedEnablerFor - Balance(lu, t) \wedge Time(ti_2)\big)\big)$$

(WoC-R17)

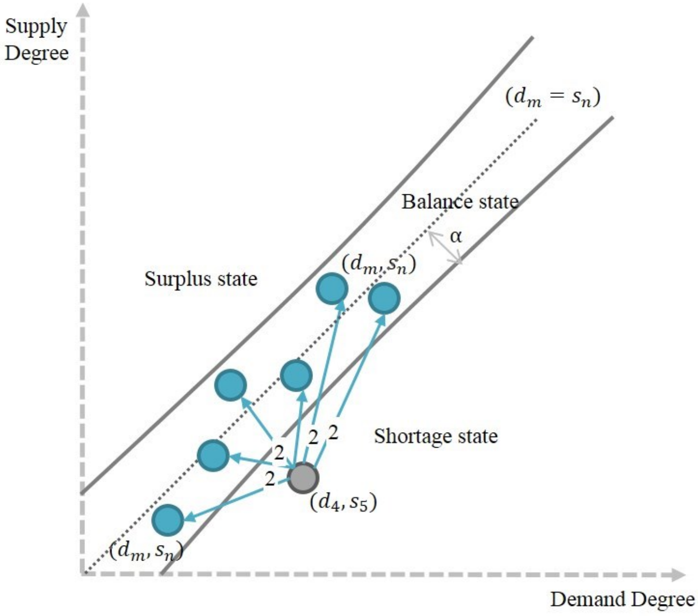


Figure 52 An Example - Transition from Shortage state to Balance state

4. Transition from **Surplus** state to Balance state:

- if $s_6 > d_3$ in the grey point (d_3, s_6);

    a) Then $d_4 = d_3 + x$ and s_6 is fixed, the gray circle of (d_3, s_6) transits to blue point of (d_4, s_6) (cf. Figure 49).

    b) Or $s_5 = s_6 - y$ and d_3 is fixed, the gray circle of (d_3, s_6) transits to blue point of (d_3, s_5) (cf. Figure 49).

    c) Or $d_m = d_4 + x$ and $s_n = s_5 + y$, where $d_m \pm \alpha = s_n \pm \alpha$, the grey point of (d_3, s_6) transits to blue circle of (d_m, s_n) (cf. Figure 53).

$$transitsU2B(t, lu) \subset (ti_1 < ti_2) \wedge \big(Time(ti_1) \wedge Task(t) \wedge KSC(ksc) \wedge learningunit(lu) \wedge isQualifiedEnablerFor - Surplus(lu, t)\big) \wedge \Big(\big(\big(move - Not - WoE(lu, ksc) \wedge move - Forward - WoW(t, ksc)\big) \vee \big(move - Backward - WoE(lu, ksc) \wedge move - Not - WoW(t, ksc)\big) \vee \big(move - Forward - WoE(lu, ksc) \wedge move - Forward - WoW(t, ksc)\big)\big) \wedge \big(isQualifiedEnablerFor - Balance(lu, t) \wedge Time(ti_2)\big)\Big)$$

(WoC-R18)

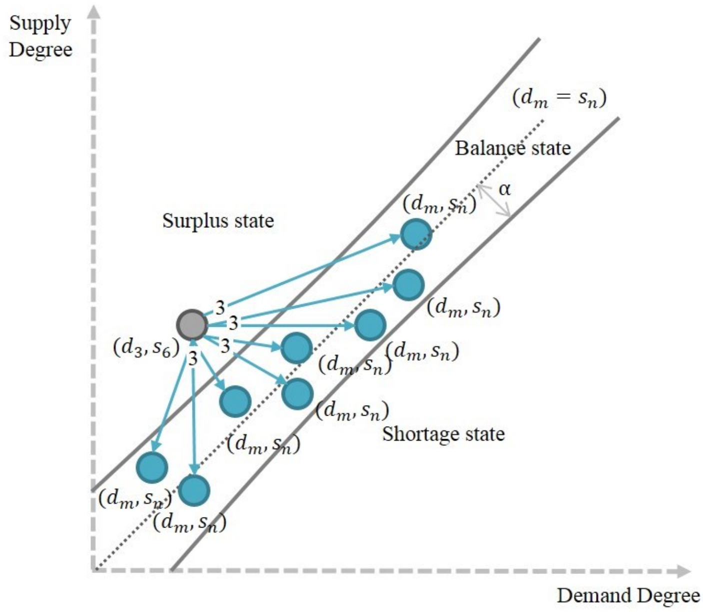


Figure 53 An Example - Transition from Surplus state to Balance state

5. Transition from **Obsolete** state to Balance state:

- if $d_0 = 0$ and s_3 is fixed in the grey point of (d_0, s_3);

  a) Then $d_2 = d_0 + x$ and s_3 is fixed, the gray circle of (d_0, s_3) transits to blue point of (d_2, s_4) (cf. Figure 49).

  b) Not applied

  c) Or $d_m = d_4 + x$ and $s_n = s_5 + y$, where $d_m \pm \alpha = s_n \pm \alpha$, the grey point (d_0, s_3) transits to blue circle (d_m, s_n) (cf. Figure 54).

$$transitsO2B(t, lu) \subset (ti_1 < ti_2) \land \big(Time(ti_1) \land Task(t) \land KSC(ksc) \land learningunit(lu) \land isQualifiedEnablerFor - Obsolete(lu, t)\big) \land \Big(\big((move - Not - WoE(lu, ksc) \land move - Forward - WoW(t, ksc)\big) \lor \big(move - Backward - WoE(lu, ksc) \land move - Forward - WoW(t, ksc)\big)\big) \land \big(isQualifiedEnablerFor - Balance(lu, t) \land Time(ti_2)\big)\Big)$$

(WoC-R19)

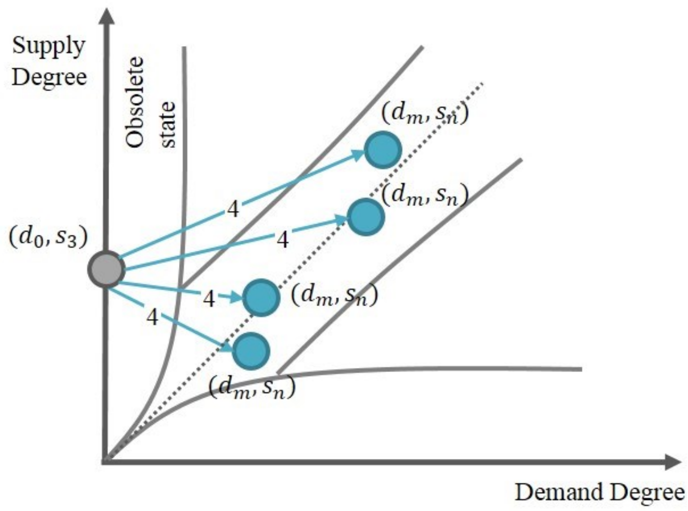


Figure 54 An Example - Transition from Obsolete state to Balance state

6.7 Summary and Discussion

This chapter elaborates how the WoE (learning function) and the WoW (performing function) are matched to each other via WoC through KSC nodes, which is the outcome of the former and requirement of the latter. To identify the result of matchmaking between supply-demand KSCs, five matching states are defined: Gap, Shortage, Surplus, Obsolete, and Balance.

As discussed in Chapter four, the conjunction of tasks of a job identified based on the job description (vertical axis), and, the required Job-KSCs based on the job specification (horizontal axis), - creates the demand space. In addition, Chapter five discusses the conjunction of the learning units of a learning field based on specific curriculum (vertical axis), and, learning outcomes (horizontal axis), - which create the supply space. Considering Demand and Supply spaces, this chapter goes through the conjunction of the two spaces which leads to match KSCs required by the WoW and the learning outcomes (i.e. KSCs obtained by learners) provided by the WoE, and ultimately infers the matching states across the WoC, which can be Gap, Shortage, Surplus, Obsolete, or Balance.

Moreover, based on the matching states of a job and a learning field that appeared on the matching space, i) four cases were revealed after analyzing a learning unit in a frame of a job (i.e. learning unit-oriented analysis), and ii) four cases for a task in a frame of a learning field (i.e. task-oriented analysis). With respect to the matching space, the tasks and learning units that need revision to transit to Balance state are anticipated.

Finally, this chapter discusses the evolution of supply-demand KSCs over time by introducing the KSC Radar (cf. Figure 47), which represents five potential transitions from time t_1

to t_2, namely, Gap, Shortage, Surplus, Obsolete and Balance, which reveal either transition to- or staying in- Balance state that is/will be required in time t_2. In addition, three interventions are defined to identify domain-specific actions that should be appropriately applied to avoid KSC imbalance.

7 Job-Know Ontology Applied in Nursing

7.1 Overview

This chapter aims to apply and evaluate the Job-Know Ontology in the nursing domain and accordingly provide proof of the concept for utilizing the Nursing Job-Know Ontology. The Nursing Job-Know Ontology has been designed, developed, tested, and deployed as an integral part of the knowledge-base of two multilingual nursing VET assistance systems: Professional Nursing Education and Training (Pro-Nursing)[38] and Web-based e-learning system for nursing students and nurses (Wissenspflege)[39]. The former was funded by the European Commission in the context of the Erasmus+ programme (2014-2016), and the latter was in cooperation with regional nursing schools in Siegen, Germany (2013-2017). The initial concept and underlying approach for developing the Nursing Job-Know Ontology had been partially investigated in the European Commission funded Innovation Transfer project, Adaptive Medical Profession Assessor (Med-Assess)[40] (2012-2014) (Khobreh , Ansari, et al. 2013), (Khobreh, Ansari, et al. 2014). Notably, it was the author's involvement in these three domain-specific projects in different capacities/roles since 2012 (i.e. researcher, work package leader, project manager, scientific coordinator), that inspired the selection and investigation of the nursing domain as a use-case of the present thesis.

Firstly, this chapter discusses how Nursing Job-Know Ontology is instantiated by using the methodology discussed in Chapter 3. Secondly, the Nursing Job-Know Ontology is specifically employed, customized, and integrated with various functional units, learning services, and different platforms in the context of the aforementioned projects. Finally, the prospective domain-independent application of the Job-Know Ontology has been investigated using the example of regional partnership project, an ontological approach for developing a Knowledge-Base of the Production-Logistic (OntoLog) (2015-2016)[41].

[38] Official project homepage: http://www.pro-nursing.eu (accessed on 07.07.2017)

[39] Official project homepage: http://www.wissenspflege.de (accessed on 07.07.2017)

[40] Official project homepage: http://www.med-assess.eu (accessed on 07.07.2017)

[41] Project webpage: http://www.eti.uni-siegen.de/ws/projekte/ontolog (accessed on 07.07.2017)

7.2 Motivation – Why Nursing Job-Know Ontology?

Worldwide highly qualified nurses are indispensable to, and, in demand by the health care sector. Shortage of skilled nurses, imbalanced skill mix and mismatches, and uneven geographical distribution of nurses like the other health human resources, are the common global challenges of healthcare systems (WHO 2016). The statistics published by the World Health Organization (WHO) show that nursing, constituting more than 50% of health professions, will face a modest decline by 2030 (WHO 2016). Germany is one of the European states confronting problems due to demographic changes resulting in a declination of nurses, despite an increase in its aging population, who are in demand of (intensive) quality care (Rothgang , Müller and Unger 2012), (United Nations 2013).

In addition, nursing is a highly standardized profession, which requires high qualification (Winterton, Le Deist and Stringfellow 2006), (Tutschner, Müskens and Wittig 2014). The quality of a healthcare system, especially hospital and home care, is strongly related to the quality of (hospital or mobile) nurses, as they constitute half of the healthcare profession (WHO 2016). The need to improve education of nurses is recognized as essential to sustain the KSCs required to be able to perform the assigned tasks competently (WHO 2016).

In the domain of nursing, the (new/emerging) KSCs supplied by the WoE occur at a different pace to the (new/emerging) KSCs demanded by the WoW leading to KSCs imbalance and resulting in unqualified nurses (WHO 2013). Nurses should be able to retrieve KSCs, obtained in their education, to perform their specific tasks. The question is how these obtained KSCs are in balance with the requested performance for doing certain tasks. Sometimes nurses suffer from a lack of KSCs to perform tasks because they have not learned the respective KSCs. When this happens frequently, it may cause difficulties for integration into a new working environment (hospital or clinic), especially when they immigrate to a new environment, nationally or internationally. Among several reasons for this is that they have not learned the required KSCs in their home nursing schools, as the related learning units had not been factored in, or, added at the appropriate time to their curricula. In this way, nurses believe that they need a system to figure out their learning needs, due to the rapid changes in evolving environment, to improve their level of KSCs (Khobreh, Nasiri and Fathi 2014), (Khobreh, Ansari and Fathi, et al. 2016).

One of the top priorities of policy initiatives in the European Union is to improve the mobility of workers and students (Tutschner, Müskens and Wittig 2014). At the tactical level, it might be seen as a way to respond to the staff shortage across countries. However, newcomers should learn the required nursing KSCs to perform the tasks assigned to them in that (host) country (place). Therefore, they need to adapt their KSCs to what is required. Hence, they need to have the educational resources to learn the required KSCs. In other words, as articulated in one of the authors' articles, "on one side the task-related competences should be extracted over time, and on the other, the appropriate learning needs to be addressed through the recommendation of learning material" (Khobreh, Ansari and Fathi, et al. 2016). In summary, there is and will remain (at least until 2030) an essential need "to train more numbers of nurses who enjoy their job, perform it in a good quality and stay in it for a long term with possibility to be mobile in the countries" (Khobreh, Ansari and Fathi 2016).

7.3 Methodology of Instantiation of Nursing Job-Know Ontology

As described in Chapter 3.6, in order to develop the A-Box of nursing and consequently instantiate the Job-Know Ontology in the specific VET and the job-specific domain, three phases should be fulfilled: specification, instantiation, and implementation. The specification phase specifies the scope, the user, the knowledge resources, and the methods of knowledge collection of the two domains of vocational education (learning field) being studied. The first step of the instantiation phase is the extraction of knowledge elements (as the individuals of the ontology) from the knowledge resources, which is performed by KA. In some cases, knowledge needs to be extracted from or created by KP using knowledge elicitation methods such as an interview, questionnaire survey, and observation. Moreover, in the instantiation phase the *SD* and *DD* values, which identify the sub-role of *requires()* and *qualifiesToObtain(),* are identified by KP. In this way, the WoW matrices (cf. Chapter 4.5) and WoE matrices (cf. Chapter 5.5) are filled out. The last step of this phase is the alignment of the Job-KSCs and learning outcome individuals using Table 15. Finally, the implementation phase is performed by OE, who provides the OWL file of Nursing Job-Know Ontology to infer and reason the KSC balance in Nursing's WoE and WoW.

In the following sections, the aforementioned phases are elaborated on in the context of nursing and the results are presented.

7.3.1 Specification of Nursing in WoE and WoW

The first phase of tailoring the Job-Know Ontology to a specific field such as nursing is identifying: i) the scope of WoW and WoE, ii) the user, who the ontology is being developed for, iii) the knowledge resources, which specify the ontological and/or non-ontological resources to extract the knowledge, and iv) the methods of knowledge collection. Table 18 is created based on Table 4 (cf. Chapter 3.6.1) and presents the four areas of the specification for the two domains of Nursing-WoW and Nursing-WoE.

Table 18 Scope, User, Knowledge Resource and Method of Data Collection for Nursing in WoW and WoE

Area	**Domain**	**Specification**
Scope	*WoW*	*ISCO-08: Nursing Associate Professionals-3221* *KldB-2010: Nursing without any specialty*[42]*-81302*
	WoE	*ISCED-F2011: Nursing and Midwifery-0913.* *EQF and DQR Level: 4* *National Scope: Nursing Education Policy developed by Ministry of Labor, Health and Social Affairs of the State of North Rhine-Westphalia (NRW)*[43]
User	*WoW*	*Nurse, nurse supervisor, job designer, WoW policy maker*
	WoE	*Nursing student studying in the NRW state of Germany, their parent, nursing teacher working in the NRW state of Germany, curriculum designer, WoE policy maker*
Knowledge Resources	*WoW*	*KldB-2010 and ISCO-08 for extracting the Main-Tasks* *Organizations' documents for extracting the Tasks* *Nursing domain expert (e.g. nursing educator or experienced nurses)*
	WoE	*Training and Examination Regulations for nurses*[44] *(KrPflAPrV)* (KrPfAPrV 2003) *which is the last updated version.* *Directive for training in healthcare and nursing, as well as in health and childcare, Affairs of the State of North Rhine-Westphalia*[45] *(AuRiKrPfNRW)* (Oelke 2003) *which is the last updated version.* *Nursing domain expert (e.g. nursing educator or experienced nurses)*
Method of data collection	*WoW*	*Interview, observation, WoW's matrices*
	WoE	*Interview, observation, WoE's matrices*

7.3.2 Identification of Nursing in KldB-2011 and ISCO-08

Nursing professionals are identified with different titles containing the word "nurse" or "nursing" such as "nursing sister", "registered nurse", "charge nurse" (International Labour

[42] In German: Gesundheits- und Krankenpflege (ohne Spezialisierung)

[43] In German: Ministerium für Arbeit, Gesundheit und Soziales des Landes Nordrhein-Westfalen

[44] In German: Ausbildungs- und Prüfungsverordnung für die Berufe in der Krankenpflege (KrPflAPrV)

[45] In German: Richtlinie für die Ausbildung in der Gesundheits- und Krankenpflege sowie in der Gesundheits- und Kinderkrankenpflege in NRW (AuRiKrPfNRW)

Office 2012). With respect to the classification of KldB, all the health-related jobs, such as nursing, are grouped in the Occupational group 8 – "Health, Social, Teaching, and Education". Considering the scope defined for the Nursing Job-Know Ontology, practical nursing with the KldB-digit of 81302 is underpinned. Figure 55 reveals this digit which identifies nursing job without specialty.

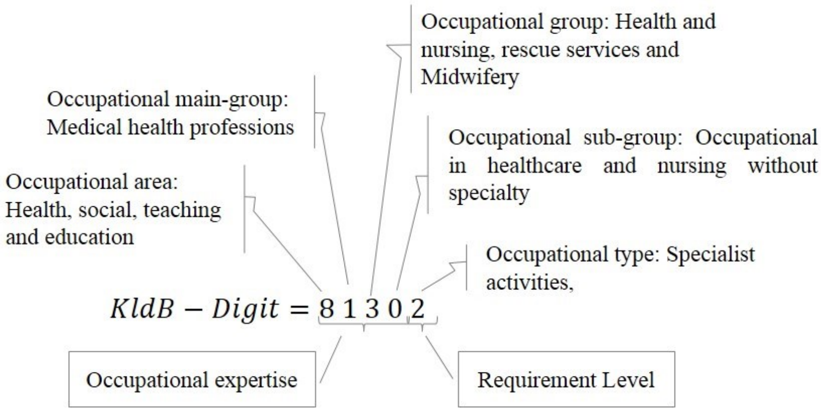


Figure 55 KldB Structure of Nursing (without specialty) and its Digit

With respect to the conversion table of KldB-2010 and ISCO-08 (cf. Chapter 4.2.3), the nursing with the digit of 81302 is mapped to "Nursing Associate Professionals" with ISCO-digit of 3221 (Bundesagentur für Arbeit 2011). Figure 56 depicts how the ISCO groups create this digit.

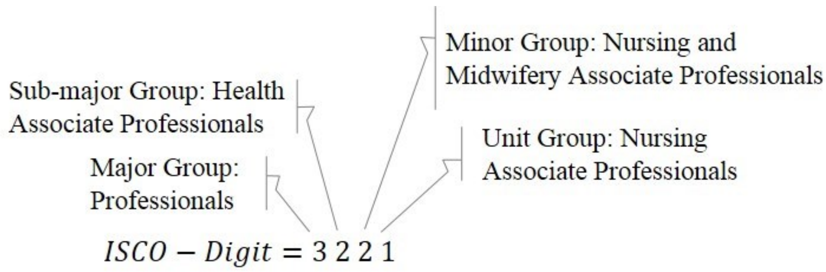


Figure 56 ISCO Structure of Nursing Associate Professionals and its Digit

Notably, the three first-right digits of the "Academic and comparable nurses"-81393 are the same as "Nursing"-81302, meaning they are in a same occupational area, occupational group and occupational sub-group, despite the fourth-digit (X_4 = 9) showing that "Academic and comparable nurses"-81393 have supervisory and leadership activities. The fifth-digit (X_5 = 2) notes that this occupation has specialist activities. Hence because practical nursing cannot be identified as KldB-81393, it is mapped to ISCO-2221 as "Nursing Professionals". This explanation does not reflect that there is no relation between KldB-81302 and KldB-81392. Nevertheless, there are similarities between these two occupations. Learners, who possess the

KSCs required for performing KldB-81392, already own some of the KSCs required to perform KldB-81302. However, learners who possess the KSCs required to perform KldB-81302 do not necessarily own the KSCs required to perform KldB-81392. The underlying reason being that the latter occupation requires special KSCs to enable the performance of the specialist activities and to act as supervisor and leader, which is not identified for KldB-81302. Table 19 presents the occupations, which should be differentiated with KldB-81302.

Table 19 Related Occupations to Nursing Associate Professional-81302 from ISCO-08 mapped to KldB-2010

KldB-2010	***ISCO-08***
Medical Specialist-81102	*Medical Assistants-3256*
Factory Nurses-81182	*Medical Assistants-3256*
Caregiver-82102	*Nursing Associate Professionals-3221*
Social Care Worker-83132	*Social Work Associate Professionals- 3412*
Home and Family Keeper-83143	*Domestic Housekeepers-5152* *Home-based Personal Care Workers-5322*
Supervisors - Health and Nursing, Rescue Services and Midwifery-81393	*Professional Nurse-2221*
Midwifery and Childbirth Care - complex specialist activities-81353	*Professional Midwife-2222*
Midwifery and Childbirth Care - specialist activities -81352	*Associate Professional Midwife-3222*
Healthcare and Nursing Assistant -81301	*Nursing Aide (clinic or hospital)-5321* *Nursing Aide (home)-5322*
Care for the Elderly (without specialization) *Helper/learning activities-82101*	*Nursing Aide (clinic or hospital)-5321* *Nursing Aide (home)-5322*
Healing education and special education - *Helper/learning activities-83131*	*Nursing Aide (clinic or hospital)-5321* *Nursing Aide (home)-5322*

7.3.3 Identification of Nursing in ISCED-2011 and EQF

With respect to ISCED-F 2011, the nursing education in the Broad Field is categorized as Health and Welfare, in the Narrow Field as Health, and in Detailed Field as nursing and midwifery. The ISCED-digit identified for nursing education is 0913. The structure of ISCED-digit of nursing education is illustrated by Figure 57.

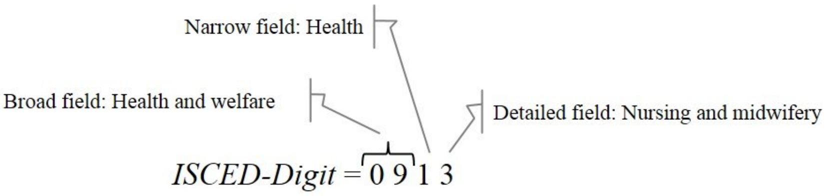


Figure 57 ISCED Structure of Nursing Education and its Digit

DQR allocates the nursing education in level four. However, there is a strong criticism from the nursing domain experts, who believed that they were not involved in the process of allocating nursing in DQR (DBfK 2014). They specified that the fourth level of DQR does not meet the competence level required by the Nursing Act and thus it should be located in the fifth level as before (DBfK 2014).

7.3.4 Instantiation of Nursing in the Frame of Job-Know Ontology

The second phase is to identify the individuals of the WoW concepts (cf. Chapter 4.4.1), WoE concepts (cf. chapter 5.4.1), and to determine the roles of the individuals in both domains to assert the A-Box of the Nursing Job-Know Ontology. In the following, the individuals of the concepts, with respect to nursing in both domains of WoW and WoE, are identified and asserted. Finally, the respective roles are used to define the semantics.

7.3.4.1 Instantiation of Nursing in the German WoW Domain

Referring to Chapter 4.4.1, the concepts defined as WoW-D1 to WoW-D9 are individualized within the nursing job. Firstly, the nursing tasks defined by KldB-81302 and ISCO- 3221 are extracted by KP and KA (cf. Appendix 2). Then the identified knowledge is implemented by OE as formalized in WoW-D1.1-WoW.D9.1 in the following:

- The nursing tasks defined by KldB and ISCO are listed by the author in Appendix 2 - Table 23. Each task requires specific KSCs to be performed (cf. WoW-D1.1).

$$Task(KldB - T - d) \supset requires - Strongly.KSC.Skill(PfMeErkErfBe) \wedge requires - Strongly.KSC.Knowledge(KNaMe) \wedge requires - Strongly.KSC.Knowledge(KPf) \wedge requires - Strongly.KSC.Skill(PfAsDuAus) requires - Moderately.KSC.Skill(BeSeEnLeBeAn) \vee requires - Weakly.KSC.Competence(PfQuReRaWiOkAu))$$

(WoW-D1.1)

- Each task has characteristics (cf. Chapter 4.3.1 – Table 9). WoW-D2.1 presents an example.

$$TaskCharacteristics(KldB-T-d) \subset hasFrequency.Frequency(Very\ Often) \vee (hasShift.Shift(Day\ shift) \wedge hasShift.Shift(Night\ shift)) \vee hasAutonomy.Autonomy(To\ a\ Great\ Extent) \vee hasInterdependency.Interdependency(\text{Sequential}) \vee hasSpecificity.Specificity(General) \vee hasCriticality.Criticality(Somewhat) \vee hasDifficulty.Difficulty(Intermediate)$$

(WoW-D2.1)

- Nursing is a job, which is identified by KldB-81302 and ISCO-3221 (cf. WoW-D3.1).

$$Job(Nursing) \equiv hasDigit.KldBDigit(81302) \wedge hasDigit.ISCODigit(3221)$$

$$Job(Nursing) \supset hasTask-Strongly.Task(KldB-81302-a) \wedge hasTask-Strongly.Task(KldB-81302-b) \wedge hasTask-Strongly.Task(KldB-81302-c) \wedge hasTask-Strongly.Task(KldB-81302-d) \wedge hasTask-Strongly.Task(KldB-81302-e) \wedge hasTask-Strongly.Task(KldB-81302-f) \wedge hasTask-Strongly.Task(KldB-81302-g)$$

(WoW-D3.1)

- The KldB-digit of "Nursing" is 81302, which represents that the job belongs to occupational area of 8, occupational main-group of 1, occupational group of 3, occupational subgroup of 0, and occupational type of 2 (cf. WoW-D4.1).

$$KldBDigit(81302) \equiv hasOccupationalArea.OccupationalArea(8) \wedge hasOccupationalMainGroup.OccupationalMainGroup(1) \wedge hasOccupationalGroup.OccupationalGroup(3) \wedge hasOccupationalSubGroup.OccupationalSubGroup(0) \wedge hasOccupationalType.OccupationalType(2)$$

(WoW-D4.1)

- The ISCO-digit of "Nursing Associate Professionals" is 3221, which represents that the job belongs to Major Group of 3, Sub-major Group of 2, Minor Group of 2, and Unit Group of 1 (cf. WoW-D5.1).

$$ISCODigit(3221) \equiv hasMajor.MajorGroup(3) \wedge hasSubMajor.SubMajorGroup(2) \wedge hasMinor.MinorGroup(2) \wedge hasUnit.UnitGroup(1)$$

(WoW-D5.1)

7.3.4.2 Instantiation of Nursing in the German WoE Domain

Referring to Chapter 5.4.1, the concepts defined in WoE-D1 to WoE-D9 are individualized within nursing education. To assert individuals of nursing education AuRiKrPfNRW (Oelke 2003) is used, which includes four learning areas[46]. Each learning area is divided into a number of sub-areas[47] and each sub-area includes learning units[48]. Table 20 specifies the names of the learning areas as well as the number of the positions underneath.

Table 20 The learning areas and the numbers of sub-areas and learning units (Oelke 2003)

Learning Area	**Sub-area**	**Learning Unit**
Nursing core tasks	5	38
Ausbildungs- und Berufssituation von Pflegenden	4	26
Zielgruppen, Institutionen und Rahmenbedingungen pflegerischer Arbeit	2	13
Gesundheits- und Krankenpflege bei bestimmten Patientengruppen (a)	n/a	15
Gesundheits- und Kinderkrankenpflege bei bestimmten Patientengruppen (b)	n/a	17
Total		109

After extracting the learning units, which should be taught in the nursing education, the learning outcomes as KSCs are identified. The main reference source which is used in this thesis is KrPflAPrV (KrPfAPrV 2003). Next, the extracted learning outcomes are related to the nursing learning units based on the knowledge extracted from AuRiKrPfNRW (Oelke 2003). Appendix 2 – Table 24 is prepared by the author to present the learning outcomes of nursing education in Germany in three categories of knowledge, skill, and competence using original terms used in (KrPfAPrV 2003) and (Oelke 2003).

In the following, the WoE concepts are instantiated.

[46] In German: Lernbereiche

[47] In German: Teilbereich

[48] In German: Lerneinheiten

- There are 109 learning units identified for learning Nursing based on NRW curriculum. WoE-D1.1 exemplifies the learning outcomes obtained by qualifying from the learning unit entitled "Skin and Body".

$$LearningUnit(HautundKoerperPflegenAnkleiden) \supset qualifiesToObtain - Moderately.LearningOutcome(KPf) \wedge qualifiesToObtain - Moderately.LearningOutcome(KNaMe) \wedge qualifiesToObtain - Weakly.LearningOutcome(PfMeErkErfBe) \wedge qualifiesToObtain - Weakly.LearningOutcome(EnUmRePfIn) \wedge qualifiesToObtain - Strongly.LearningOutcome(PfPeAu)$$

(WoE-D1.1)

- Each learning unit has its own characteristic (cf. Chapter 5.3.1). WoE-D2.1 exemplifies one of the learning units that is entitled "Skin and Body".

$$LearningUnit(HautundKoerperPflegenAnkleiden) \equiv needsHour.LearningHour(46) \vee (qualifiesToObtain - Strongly.LearningOutcome(KPf) \wedge qualifiesToObtain - Moderatly.LearningOutcome(KNaMe) \wedge qualifiesToObtain - Strongly.LearningOutcome(PfMeErkErfBe)) \vee isDeliveredthrough.UnitType(Lecture) \vee \exists_{\geq 1} isAssessedthrough.AssessmentType(Examination) \vee \exists_{\geq 1} hasReadingList.ReadingList(PflegeHeute) \vee \exists_{\geq 1} hasLearningPlace.LearningPlace(LearningOrganization)$$

(WoE-D2.1)

- One of the nursing curricula, AuRiKrPfNRW, is taught in the NRW state of Germany. This curriculum consists of 109 learning units to learn Nursing. WoE-D3.1 exemplifies a learning unit of AuRiKrPfNRW entitled "Skin and Body"[49].

$$Curriculum(AuRiKrPfNRW) \equiv consistsof.LearningUnit(HautundKoerperPflegenAnkleiden)$$

(WoE-D3.1)

- Learning field of nursing, which has ISCED-0913, includes AuRiKrPfNRW curriculum. This field is taught at school and in the work place. Therefore, its learning style is mixed (cf. WoE-D4.1).

$$DetailedField(NursingEdu) \equiv hasCurriculum.Curriculum(AuRiKrPfNRW) \wedge hasLearningStyle.LearningStyle(MixedLearning) \wedge \exists_{=1} hasDigit.ISCEDdigit(0913)$$

(WoE-D4.1)

[49] In German: Haut und Körper pflegen, ankleiden

- The ISCED-digit of nursing education is 0913, which has Broad Field of 09, narrow field of 1 and detailed field of 3. Nursing education stands on the 4-level of EQF/DQR (Cf. WoE-D2.1).

$$ISCEDdigit(0913) \equiv hasFirstDigit.BroadField.BroadField(09) \wedge hasSecond.NarrowField(1) \wedge hasLast.DetailedField(3) \wedge \exists_{=1} has\mathrm{EQ}F.EQF(4)$$

(WoE-D5.1)

- Refers to Appendix 2 – Table 24, 16 learning outcomes should be obtained by learning nursing curriculum of AuRiKrPfNRW (Oelke 2003). WoW-D6.1 represents these learning outcomes.

$$KSC \equiv consistsOf.Knowledge(KPf) \wedge consistsOf.Knowledge(KNaMe) \wedge consistsOf.Knowledge(KSo) \wedge consistsOf.Knowledge(KRePoWi) \wedge consistsOf.Skill(PfMeErkErfBe) \wedge consistsOf.Skill(PfAsDuAus) \wedge consistsOf.Skill(PfPeAu) \wedge consistsOf.Skill(PfWiErAu) \wedge consistsOf.Skill(LeAninAr) \wedge consistsOf.Skill(BeSeEnLeBeAn) \wedge consistsOf.Competence(UnBeAnPf) \wedge consistsOf.Competence(EnUmRePfIn) \wedge consistsOf.Competence(PfQuReRaWiOkAu) \wedge consistsOf.Competence(MeDiThMw) \wedge consistsOf.Competence(EnPfb) \wedge consistsOf.Competence(GTZuAr)$$

(WoC-D1)

7.3.5 3-D Space of Task, KSC and Learning Unit

As described earlier, the A-Box of Nursing Job-Know Ontology is instantiated and the associated OE has implemented the values of the matrices in the T-Box of the ontology. In fact, the semantic demand and supply spaces are asserted after instantiating the individuals and defining their roles. Consequently, matching space is inferred based on the sub-roles of *isQualifiedEnablerFor()* (cf. Chapter 6.5). Ultimately, the 3-D space of TkscL is inferred with respect to the conjunction of the aforementioned spaces. In the following, an example is given to clarify how the Balance states are identified on the matching space.

(1)	It is asserted that	$requires - Strongly(KldB - NT - d, KPf)$ (WoW-R5)
(2)	It is asserted that	$qualifiesToObtain - Moderately(HautundKoerperPflegenAnkleiden, KPf)$ (WoE-R3)
(3)	It is inferred that	$isQualifiedEnablerFor - Shortage(HautundKoerperPflegenAnkleiden, KldB - TN - d)$ (WoC-R1)

Moreover, the matching space is analyzed by considering two orientations: Using the example of nursing education, the state of $LearningUnit(HautundKoerperPflegenAnkleiden)$ in a nursing job is initially analyzed (i.e. Learning Unit-Oriented Analysis) as detailed below:

(1)	Identification of learning outcomes of the learning unit	$LearningUnit(HautundKoerperPflegenAnkleiden\ ) \supset qualifiesToObtain - Moderately.LearningOutcome(KPf) \wedge qualifiesToObtain - Moderately.LearningOutcome(KNaMe\ ) \wedge qualifiesToObtain - Weakly.LearningOutcome(PfMeErkErfBe) \wedge qualifiesToObtain - Weakly.LearningOutcome(EnUmRePfIn) \wedge qualifiesToObtain - Strongly.LearningOutcome(PfPeAu)$ (WoE-D1)
(2)	Inferring the matching states of the learning unit and the tasks via the KSC identified in (1)	$isQualifiedEnablerFor - Shortage(HautundKoerperPflegenAnkleiden\ , KldB\ - NT - b)$ $isQualifiedEnablerFor - Balance(HautundKoerperPflegenAnkleiden\ , KldB\ - NT - c)$ $isQualifiedEnablerFor - Surplus(HautundKoerperPflegenAnkleiden\ , KldB\ - NT - g)$ (WoC-R1)
(3)	Learning Unit-Oriented Analysis: Case IV	$MS4LU - inMixed(HautundKoerperPflegenAnkleiden) \subset\ isQualifiedEnablerFor - Shortage(HautundKoerperPflegenAnkleiden\ , KldB\ - NT - b) \wedge isQualifiedEnablerFor - Balance(HautundKoerperPflegenAnkleiden\ , KldB\ - NT - c) \wedge isQualifiedEnablerFor - Surplus(HautundKoerperPflegenAnkleiden\ , KldB\ - NT - g)$ (WoC-R10)

Alternatively, there is a possibility to analyze the matching states of the task. The Task-Oriented Analysis for $Task(KldB - \mathrm{NT} - d)$ is described as follows.

(1)	Identification of KSC of the task	$Task(KldB - T - d) \subset requires - Strongly.KSC.Skill(PfMeErkErfBe) \wedge requires - Strongly.KSC.Knowledge(KNaMe) \wedge requires - Strongly.KSC.Knowledge(KPf) \wedge requires - Strongly.KSC.Skill(PfAsDuAus) requires - Moderately.KSC.Skill(BeSeEnLeBeAn) \vee requires - Weakly.KSC.Competence(PfQuReRaWiOkAu))$ (WoW-D1)
(2)	Inferring the matching states of the learning units and the task via the KSC identified in (1)	$isRequiredToBeQualifiedIn - Shortage(\ KldB\ - NT - d, HautundKoerperPflegenAnkleiden\ ,)$ $isRequiredToBeQualifiedIn - Balance(\ KldB\ - NT - d,\ \ Atmen)$ $isRequiredToBeQualifiedIn - Shortage(\ KldB\ - NT - d,\ \ PflegePlanUndDokumentieren)$ (WoC-R1-reversed)

(3)	Task-Oriented Analysis: Case II	$MS4LU - inShortage(KldB\ - NT - d) \subset isRequiredToBeQualifiedIn - Shortage(\ KldB\ - NT - d, HautundKoerperPflegenAnkleiden\ ,) \wedge isRequiredToBeQualifiedIn - Balance(\ KldB\ - NT - d,\ Atmen) \wedge isRequiredToBeQualifiedIn - Shortage(\ KldB\ - NT - d,\ PflegePlanUndDokumentieren)$ (WoC-R12)

Finally further analysis, (for example: to tackle the problem of shortage of task and learning unit), a Transition Action, should be completed and include a focus on looking at what are the possible consequences. The steps to providing the answer are specified below.

(1)	Select the task and the learning unit	$Task(KldB - NT - d)$ (WoW-D1) $LearningUnit(HautundKoerperPflegenAnkleiden)$ (WoE-D1)
(2)	Select the Transition Action	The potential actions are • Action a: WoW decreases the demands of $Task(KldB - NT - d)$ for $KSC(KPf)$ to have *DD*=2, • Action b: WoE increases $KSC(KPf)$ via revising $LearningUnit(HautundKoerperPflegenAnkleiden)$ to have *SD*=3, or • Action c: WoW decreases the demands of $Task(KldB - NT - d)$ for $KSC(KPf)$ to have *DD*=1 and WoE increases $KSC(KPf)$ via revising $LearningUnit(HautundKoerperPflegenAnkleiden)$ to have *SD*=1. In this case, the action **b** is selected by KP.
(3)	It is inferred that	$transitsS2B(KldB - NT - d, HautundKoerperPflegenAnkleiden)\ \subset move - Forward - WoE(HautundKoerperPflegenAnkleiden, KPf) \wedge move - Not - WoW(KldB - NT - b, KPf)$ (WoC-R17)
(4)	The consequence is	$(ti_1 < ti_2) \wedge time(ti_2) \wedge qualifiesToObtain - Strongly(HautundKoerperPflegenAnkleiden, KPf)$

7.4 Onto4Nursing System for Utilizing Job-Know Ontology in Nursing

The “Ontological Knowledge-Base for Nursing Assistance Systems” (Acronym *Onto4Nursing*) is a KSC recommender and learning assistance system, which consists of four main building blocks:

- **Knowledge-base** including the Nursing Job-Know Ontology,
- **Functional units**, namely, Assessment Unit (AU), Browser Unit (BU), and Collaboration Unit (CU),
- **Learning services** in different styles of e-learning and serious game, namely, *e-Onto4Nursing* and *G-Onto4Nursing*, and
- **Presentation platforms/medium**, including web-portals and/or mobile applications.

Figure 57 depicts the overall architecture of the Onto4Nursing. Table 21 elaborates the Figure components.

The *Onto4Nursing* system was developed using the key findings of comprehensive needs and requirements analyses performed in the domain of nursing (mainly in Germany and partially across other European states) and within the context of the aforementioned projects, Med-Assess, Pro-Nursing, and Wissenspflege, from 2012 to 2016.

The Nursing Job-Know Ontology was developed as described earlier and evaluated by regional domain experts (experienced nurses and nursing educators) in Siegen and in the federal state of NRW, as well as by national domain experts (nursing educators and curriculum designers) in several iterations in addition to the frame of the aforementioned projects.

Table 21 describes the Onto4Nursing system based on the components given in Figure 58 in details. It elaborates on related system building blocks and indicates the evaluation process reported in the authors' publications, technical reports, and supervised theses.

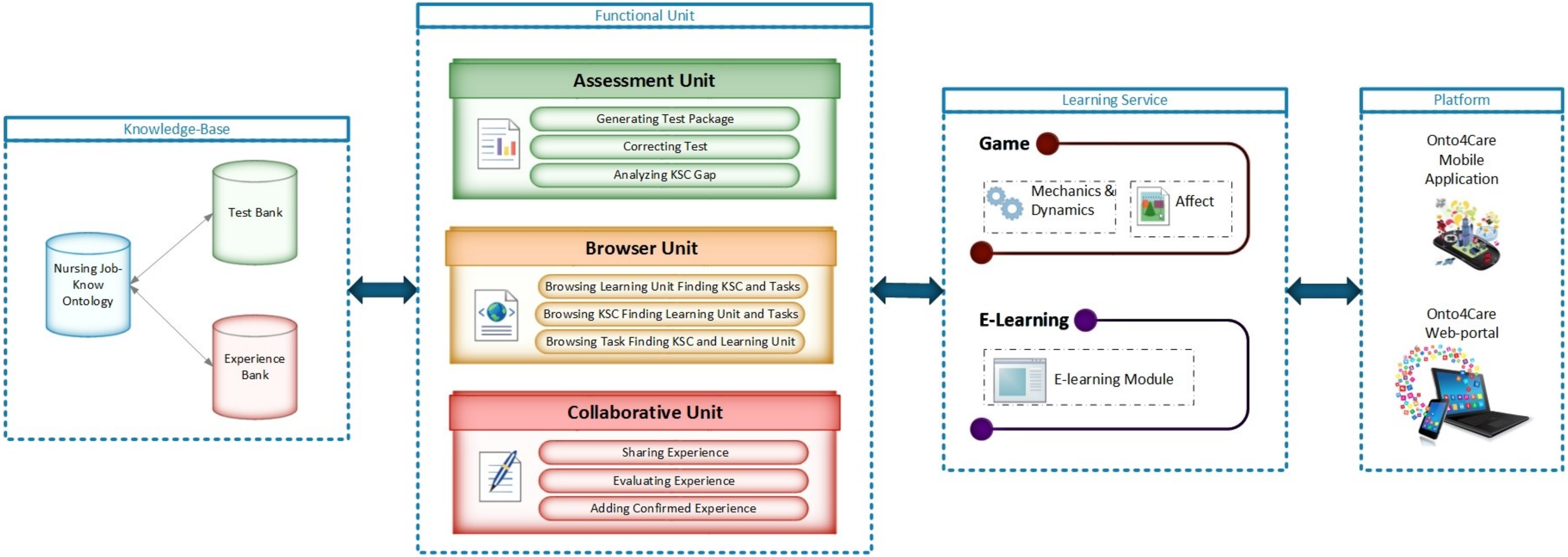


Figure 58 Onto4Nursing System - Conceptual Architecture

Table 21 Description of Onto4Nursing Knowledge-Base, Units, Interface and Platform

Onto4Nursing System	***Detail***	***Description***	***Implemented and Evaluated Status***
Knowledge-base	*Nursing Job-Know Ontology*	*Nursing Job-Know Ontology includes three super-classes of nursing in WoW, nursing in WoE and also nursing in WoC. The steps to instantiate the Job-Know Ontology towards Nursing Job-Know Ontology have been described earlier (cf. Chapter 7).*	*The content and structures was evaluated by the domain expert in Pro-Nursing and Wissenspflege projects.*
	Test Bank	*To assess the KSC level, more than 800 questions in German have been generated in connection with the KSCs, tasks and learning units. These questions were stored in the Test Bank.*	*The questions were generated in Wissenspflege project and evaluated by the nursing teachers and educator of the NRW federal state.*
	Experience Bank	*The experiences in relation to the nursing tasks have been stored in the Experience Bank database. Each experience is related to a task and learning unit.*	*It was evaluated in the frame of Wissespflege project.*
Functional Unit	*Assessment Unit*	*To assess the KSCs of nursing students/ nurses, this unit generates the test packages based on the nursing tasks and nursing learning units. Then the test result will be corrected and analyzed to provide feedback on KSC level for the end-user (nursing student, nurse, and supervisor).*	*This unit was developed and evaluated in Wissenspflege project.*
	Browser Unit	*Via this unit, the end user can select and browse learning units with two indications, firstly KSC related learning outcomes, and secondly task related requirements. Alternatively, the end-users can browse the nursing tasks to*	*This unit was developed and evaluated in the frame of the Pro-Nursing project.*

Onto4Nursing System	***Detail***	***Description***	***Implemented and Evaluated Status***
		find out what KSCs and consequently learning units are required to be able to perform the selected tasks.	
	Collaboration Unit	*This unit provides a facility for nurses and supervisors to share their experience, which they collected doing their tasks. These experience elements, after passing the evaluation and confirmation steps, will be used by the nursing students and teachers as new/ emerging learning materials.*	*This unit was developed and evaluated in the frame of Wissenspflege project.*
Learning Service	*E-learning (E-Onto4Nursing)*	*The Onto4Nursing was first developed as an e-learning system for continuous learning and assessing the nursing fields in the NRW federal state of Germany. The focus of the system is not just nursing students, however, the nurses, who aim to improve their KSCs via practicing, reviewing or obtaining specific learning units, or those who want to share their experiences, may engage in the system. The aforementioned Onto4Nursing's units are accessible via the mobile or web-portal platforms.*	*The e-learning interface was developed in the frame of Wissenspflege project. The usability and functionality of the system were evaluated by the end-users and domain experts in several iterations.*
	Game (G-Onto4Nursing)	*To utilize persuasive technology for more engagement of the end-users, the Onto4Nursing was developed as a serious game. The Game (G-Onto4Nursing) includes "a scoring system to collect the player points, badges system to analyze the progress of the player and provide the new badge to him/her, and also Leader board to present the place of the player in comparison with the other classmates"* (Khobreh, Ansari and Fathi 2016).	*The game interface engine was developed in the frame of Wissenspflege project. The usability and functionality of the system were evaluated by the end-users and domain experts in several iterations.*

Onto4Nursing System	***Detail***	***Description***	***Implemented and Evaluated Status***
Platform	*Web-Portal*	*The e-learning and game developed under Onto4Nursing system was implemented as a web-portal to be accessible via internet browsers.*	*The usability of the web-portal was evaluated to confirm that the system works on all major internet browsers.*
	Mobile Application	*The Onto4Nursing system was also implemented as a mobile application on Android.*	*The usability of the web-portal was evaluated to confirm that the system works on mobile devices.*

7.5 Discussion on Domain Independent Application of Job-Know Ontology

The Job-Know Ontology is domain independent, this means that the meta-model is specified, conceptualized, and formalized regardless of being fitted to a specific job or education. Therefore, the ontology can be instantiated for developing the Job-Know Ontology for a specific job and related education domain such as nursing.

Considering the domain independent ontology creating an approach and domain specific contents, there is an opportunity to extend the study of the domains and to add more jobs and education fields using a similar approach applied in the domain of nursing i.e. by defining the relation between their tasks, KSCs, and learning units.

The above-described approach was the core idea of the project entitled “Ontological Approach for Developing a Knowledge Base of the Production-Logistic” (Acronym: OntoLog, 2015-2016) done in cooperation with regional partners in the area of Siegen. OntoLog uses the Job-Know Ontology and the lessons learned with the creation of the nursing edition towards instantiating the Production-Logistics Job-Know Ontology (cf. Figure 59).

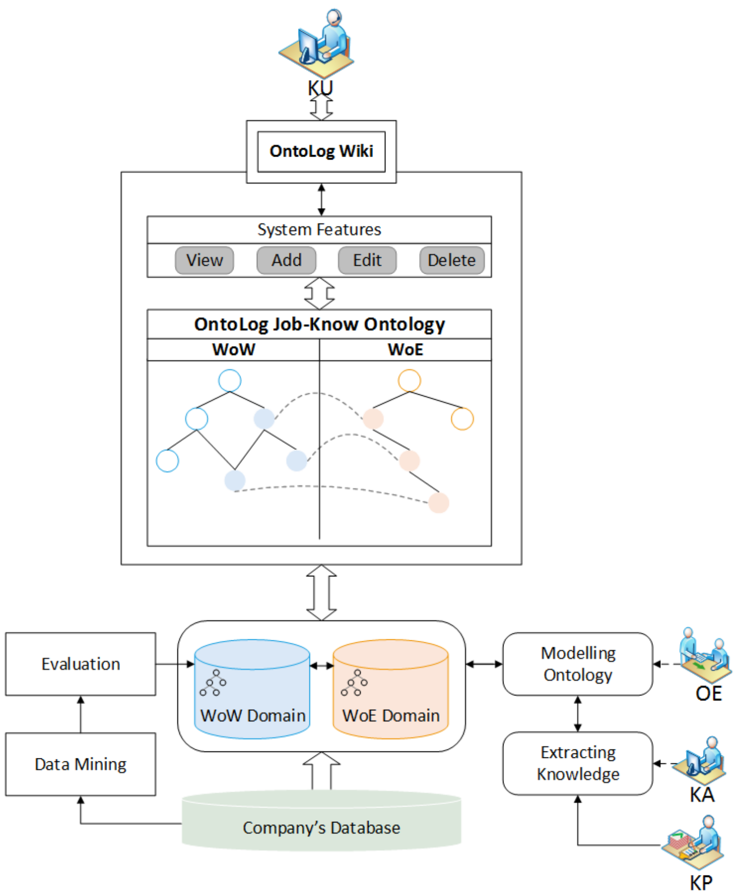


Figure 59 Conceptual Image of OntoLog Job-Know Ontology

The tasks, KSCs, and learning units were defined by the industrial partners and then were reengineered, formalized and developed by the associated KA and OE to infer whether learning units provided by the company are in balance to perform tasks, whether they are updated enough, or if there is a need to improve the materials based on the matching states inferred.

The software prototype, which was successfully developed in the context of the OntoLog, was positively evaluated by the end-user and board of experts. Notably, due to intellectual property rights, the software screen-shots and evaluation results are kept confidential.

7.6 Summary

This chapter specifically describes how the Job-Know Ontology can be instantiated by obtaining knowledge from nursing jobs and related education domains. Based on the methodology established in Chapter 3, the specification, instantiation and implementation phases of the nursing WoW and WoE have been performed.

The implementation results are presented in this chapter, and show how much nursing tasks are in balance with nursing learning unit. Consequently, the nursing job market is faced with under-qualified, qualified, or overqualified staff or applicants. In addition, the results indicate which learning units and tasks need to be considered by the WoW and WoE to successfully manage the transition from the As-Is state to the Balance state (desired state).

Furthermore, it is revealed that the Job-Know Ontology can be extended and instantiated to other jobs and education such as production-logistics (Cf. Chapter 7.8). Thus, the Job-Know Ontology framework may be used to instantiate different jobs and may support matching different jobs to different education (i.e. Global Job-Know Ontology).

8 Conclusion and Future Work

This chapter presents the key findings and results of the thesis and later discusses the open issues for potential future contributions.

8.1 Key Findings: Summary and Discussion

The present thesis has established a Job-Know Ontology to represent the WoW and WoE towards inferring whether what is supplied by the WoE, particularly VET and not HE, is in balance with what is demanded by the WoW. As such, firstly the existing models, concepts, and ontologies are studied and later the meta-model of the Job-Know Ontology is conceptualized. With respect to outcome-oriented education approaches, what is identified is that the melting point of the WoW and WoE is KSC. KSC is both the output of the learning process, and, the input of performing a job. This melting point creates the WoC, which includes the supplied and demanded KSCs, and determines their balance states. Considering the main objectives and research questions (cf. Chapter 1), the key findings of the thesis are specified as:

Key Finding-1: To develop the T-Box (i.e. concepts and roles) and A-Box (i.e. individuals) of the Job-Know Ontology, a methodology is developed (cf. Chapter 3). This methodology is inspired from the ontology development methodologies (Chapter 2.3.2), particularly NeOn methodology. However, the instantiation phase to develop the A-Box for the domain of interest is a novel approach, introduced in the context of the present thesis. The T-Box of the ontology is conceptualized domain-independent to provide the opportunity to populate the Job-Know Ontology in different job and education domains, while the A-Box is domain-dependent. Therefore, the instantiation phase should be taken into account to first individualize the ontology in a specific domain, and consequently extend it (to a Global Job-Know Ontology) by adding further domains to the ontology. This methodology is evaluated in two different job contexts: nursing and production-logistics (cf. Chapter 7).

Key Finding-2: The WoW consists of three main concepts of *Job*, *Task,* and *Job-KSC* based on the definition of the Job-Know Ontology (cf. Chapter 4). According to the T-Box of the WoW domain, the *Job* concept is related to the *Task* concept via *hasTask()* role. This role is a super-role, which includes detailed roles that identify the dependency of the task to the job (cf. Chapter 4.3.1 – Table 8). Moreover, *Task* concept is related to *Job-KSC* concept via the super-role of *requires()*, where the sub-roles identify how much a task requires the Job-KSCs (cf. Chapter 4.3.2 – Table10). Two values of *TD* and *DD* are defined to shape the semantic relations between job and its tasks, and task and required Job-KSCs respectively.

Key Finding-3: To populate and instantiate the WoW domain of the Job-Know Ontology eight matrices are established (cf. Chapter 4.5). In fact, the matrices are used to infer four cases identifying: i) a unique Job-KSC to perform the given job, ii) a unique Job-KSC to perform the given task, iii) the job-KSC with the strongest effect on performing the given job, and iv) the job-KSC with the strongest effect on performing the given task (cf. Chapter 4.x).

Key Finding-4: The WoE consists of three main concepts of *Curriculum*, *Learning Unit*, *Learning Outcome* defined by the Job-Know Ontology. The *consistsOfLU()* role connects *Curriculum* and *Learning Unit*, and the super-role of *qualifiesToObtain()* connects the *Learning Unit* to *Learning Outcome*. This super-concept is subdivided into the *Strongly*, *Moderately*, *Weakly* and *Not* sub-roles, based on the introduced *SD* value, which determines to what extent a learning unit qualifies learners to obtain a specific learning outcome (cf. Chapter 5.3.2 Table 13).

Key Finding-5: The WoE is instantiated by using the seven matrices defined in Chapter 5.5. The matrices are used to infer four cases: i) this learning unit uniquely qualifies learners to obtain the desired learning outcome, ii) the learning outcome is uniquely obtained from the given learning unit, iii) the learning outcome is strongly obtained from learning the given curriculum, and iv) the learning outcome is strongly obtained from learning the specific unit.

Key Finding-6: To align the WoW and WoE via KSC, a Conversion Table is provided (cf. Chapter 6.3 – Table 15), which elaborates how Job-KSCs (demand side) should be related to the learning outcomes (supply side). To do so, five actions based on the combination of 5 conditions are defined (cf. Chapter 6.6.1 – Table 17).

Key Finding-7: The conjunction of the demand space (i.e. Task as horizontal axis and Job-KSC as vertical axis) and supply space (i.e. Learning Unit as horizontal axis and Learning Outcome as vertical axis) creates the 3-D space of Task (y-axis), KSC(x-axis) and Learning Unit (z-axis) (cf. Chapter 6.4.3 – Figure 44). In this way, the matching space is inferred, and represents the matching states of the tasks and the learning units via KSCs. The role of *isQualifiedEnablerFor()* is inferred based on applying logic *And* on two roles of *requires()* and *qualifiesToObtain()*, which relates the learning unit to the task semantically. This super-role is subdivided into the five sub-roles, which identify the matching states of the task and learning unit as Gap, Shortage, Surplus, Obsoleteness, or Balance. These sub-roles and matching states together provide the opportunity to analyze which learning unit and/or task needs to be revised by the WoW and/or WoE. The learning unit-oriented and task-oriented analyses on the matching space define eight cases (cf. Chapter 6.5). Transition actions (cf. Chapter 6.6.1 – Table 17) should be anticipated based on these eight cases.

Key Finding-8: To transit to/stay in Balance state, six roles are defined, which move the task/learning unit forward, backward or, if they are in Balance, does not move them (cf. Chapter 6.6.1). These roles fundamentally are used to transit from an imbalance state to Balance, or stay in Balance state if they were here previously. Five transition ways are defined, that utilize the aforementioned role to move to Balance state in the future.

Key Finding-9: The Job-Know Ontology is instantiated in the nursing domain and partially in production-logistics, where the methodology and the concepts and roles of the Job-Know Ontology are tested. The result of implementation presents that the Job-Know Ontology is a novel approach to formalize the education and job domains with the perspective of analyzing the matching state between these two domains via the WoC.

8.2 Future Work: Open Issues and Potentials

With respect to the key findings of the present thesis and the restrictions mentioned in Chapter 1, the open issues of the thesis and recommendations of the author for future work are expressed in the following.

Open Issue-1: To model the WoW further, one role of *isRelatedToJob()* can be defined to relate the jobs, which have similar tasks and thereby require similar KSCs (i.e. job similarity detection). In this way, it can be inferred, which tasks of the origin job are also described by the selected job. In the case of staff shortage in the origin job, there is a recommended job(s) with staff that may switch to the origin job. Here, the staff also need to obtain required KSCs, but they should already have some of the required KSCs, as some of the tasks of the jobs are similar. The best-fit jobs can then be inferred and then will be recommended to the employees in the case of staff shortage in a certain job (job sector across the job market).

Open Issue-2: To model the WoE further, one role of *isRelatedToLF()* can be defined to connect the related learning fields that have similar learning units and, as a result, similar outcomes (i.e. Education similarity detection). Further it is possible to infer which learning field is closer/ the closest learning field to the original learning field in terms of providing the expected learning outcomes. Learners who want to switch to another learning field can identify the KSCs to be obtained, and to what extent the KSCs obtained in their original learning field can be reused in the new learning field. In cases where there is a shortage of job applicants who have graduated from a specific learning field (e.g. nursing education) to perform a specific job (e.g. nursing), it can be inferred and recommended which learning field might be the good-fit for this job. Consequently, the organization may hire graduates from the closest learning field (e.g. assistant doctor or social caregiver) to the origin (e.g. nursing). Notably, this raised over- or under-qualification problem should be further investigated.

Open Issue-3 The ontology creating and matching process of WoW and WoE via WoC described by Chapter 6.3, is performed manually. There is a possibility to provide an ontology matching algorithm to make it (semi-) automatic. To do so, it should be decided whether the alignment is based on the similarity between the terms or the meaning (i.e. term associations).

Open Issue-4: There is also room to extend the scope of the domains and apply the Job-Know Ontology across countries considering multilingual non-ontological and ontological resources, as well as the diversity of national occupations and VET systems. For example, the scope of the WoW domain is Germany, while the scope of the WoE domain is France (i.e. imagine an individual graduated in France wanting to perform a job in Germany). The inference mechanism to analyze whether or not the KSCs supplied and demanded are in balance is the same as discussed in this research. However, the important issue is aligning the learning outcomes, which are in French (in our example) and the job-KSCs that are contextually and terminologically in German.

Open Issue-5: Forecasting future demand to supply KSC in right time is a challenge. One potential future work is to record the evolution of the Job-Know Ontology to model the track of changes and infer changes not only in the demand but also in the supply side. Changes to tasks may reveal that the job has reformed to another job, split into more than one job, or has even disappeared, based on the needs of the WoW. Tracking the changes of tasks in our ontology can provide the opportunity for modeling in the future. Alternatively, tracking changes in learning units shows how a learning field is reformed over time and thus, we may model the future of the field based on the history of changes and the forecasted demands.

To conclude, the author believes that the present research facilitates communication between the WoW and WoE, infers the imbalance problems, and defines an action to transit to the Balance state. Considering the key findings and the open issues, the present thesis deepens the insight into the macro-matching process to overcome the problem of skill imbalance or mismatch using Job-Know Ontology.

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10 Bibliography of Technical Reports/ Theses

This chapter presents the technical reports and theses, which are co-supervised by the author and have been affected on the results and finding of my thesis.

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11 Appendix

11.1 Summary of Methodologies of Ontology Development

Table 22 presents the methodologies, which are studied and summarized by the author. The summary and discussion on the methodologies are given by chapter 2.3.2.

Table 22 Methodologies of Ontology Development

Abstract	**Source**
UPON Lite is a lightweight methodology for rapid (ad-hoc) ontology engineering based on "a lean, incremental process conceived" to develop ontology by end-user and domain expert, without a specific need to have ontology engineer on board. "UPON Lite is a derivation of the full-fledged UPON Methodology", focusing on non-ontology experts and following six steps of engineering process; step 1: Domain terminology (i.e. listing the domain terms), step 2: Domain glossary (i.e. defining a textual description and possible synonym of the terms), step 3: Taxonomy (i.e. determining the terms in a hierarchical structure), step 4: Prediction (i.e. identifying the properties from the glossary and connect them to the respected entities), step 5: Parthood (i.e. defining the part and whole semantic relation), and step 6: Ontology (i.e. coding ontology formally).	(De Nicola and Missikoff 2016)
The NeOn methodology includes a glossary (i.e. 59 processes and activities), a set of nine scenarios, two ontology network life cycle models, and a set of guidelines. The scenario-based methodology, NeOn, defines the processes for developing (networked) ontologies on the light of reusing and evolving the ontology in distributed environment with considering the different people (i.e. domain expert and ontology practitioners) in process of building the ontology. The nine-NeOn scenarios are described below: • Scenario 1: From specification to implementation: building the ontology from scratch. This scenario is the core part of the methodology and should be combined with the other scenarios. The first activity of the first scenario called *specification* is to provide the ontology requirement specification document, which includes the purpose, the scope, and implementation language. Besides, competency questions and pre-glossary of terms should be defined within this activity. Afterward, the knowledge resources (i.e. ontologies, non-ontological resources, and ontology design patterns) will be distinguished. The type of knowledge resource(s) identify which scenarios should be followed. The second activity of the first scenario is called *conceptualization* is to structure the descriptive	(Suárez-Figueroa, Gomez-Perez and Fernandez-Lopez 2011)

Abstract	Source
knowledge into a conceptual model. The third activity is *formalization* is to transform the conceptual model into a semi-computable model, and the last activity *implementation* is to transform the semi-computable model into a codified ontology. • Scenario 2: Reusing and re-engineering non-ontological resources. As mentioned earlier, under the light of the type of candidate knowledge resource(s) identified in requirement specification document, a scenario will be followed. In case, the type of knowledge resource(s) is non-ontological, then the second scenario encompasses two main activity, namely, i) Non-Ontological Resource Reuse and ii) Non-Ontological Resource Reengineering should be performed. Within the first activity, the non-ontological resources will be identified, then the set of the candidate will be assessed, and finally, the most appropriate ones will be selected. The first activity can be considered as part of the first activity of the first scenario (specification). Within the latter activity; firstly, the selected non-ontological resource will be analyzed and transformed into a conceptual model, this part is called conceptualization in the first scenario. Afterward the first scenario will be followed. • Scenario 3: Reusing ontological resources. In case the type of candidate knowledge identified in ORSD is ontological, then this scenario will be followed. Within the specification activity, the ontological resources will be searched, assessed, and comprised. Then a set of ontological resources will be selected. There are two main ways; one is the selected ontological resources will be used as they are, the second one is re-engineering, merging and integrating activities are required to provide a new ontological resource. If the ontology developer finds and selects an ontological resource, which fits with the specifications, then there is no need to perform the conceptualization, formalization and implementation activities of the first scenario. While, if the second way should be followed and there are some needs to customize an existing ontological resource and generate a new one then the scenario 4, 5, 6, 7, 8 or 9 should be followed based on the needs. • Scenario 4: Reusing and re-engineering ontological resources. In case the type of the candidate knowledge resources is ontological, and the selected ontological resources should be modified to serve the intended purpose, this scenario should be followed. Firstly, the ontological resource reuse process including ontology search, ontology assessment, ontology comparison, and ontology selection as part of scenario 3 should be followed. Depending on the ontological resource characteristics that have to be changed, re-specification, re-conceptualization, re-formalization or re-implementation (the core activities of developing ontology) should be performed as re-engineering process on the selected ontological resources. Then the ontology developer will restructure, customize and/or modify the selected ontological resource and provide the intended one, which fits with purpose. Afterward, depending on the level of re-engineering and restructuring, the forward engineering will be applied. • Scenario 5: Reusing and merging ontological resources. In case the type of the candidate knowledge is ontological, the ontological resource reuse process (scenario 3) is applied, and suitable ontological resources are selected, then the alignment between the	

Abstract	Source
selected ontologies should be identified. Finally, refers to the defined alignments, the ontologies will be merged to obtain a new ontological resource, which fits with the purpose. Depending on the characteristics of the selected ontological resources, the process of re-engineering, restructuring and forward engineering should be applied to obtain the new ontological resource. • Scenario 6: Reusing, merging, and re-engineering ontological resources. This scenario consists of the process of ontological resource reusing to select the appropriate resources and then re-engineering the resources in accord with the needs, and finally aligning and merging the ontological resources and implementing the resultant ontology. • Scenario 7: Reusing ontology design patterns (ODPs).The pattern of the best practices is available online in the libraries for ontology development to reuse them. Ontology developer should follow the process of reusing the ontological resources to find the best fit in a form of ODP if there is any. The pattern may be used in the level of conceptualization, formalization or even implementation. • Scenario 8: Restructuring ontological resources. This scenario can be performed separately or as part of scenario 4. Scenario 8 consists of i) ontology modularization activity to create different ontology modules, ii) ontology pruning activity to prune the unnecessary branches, iii) ontology enrichment activity to extend the ontology concepts and relations and/or, iv) ontology specialization activity to specialize the branches that need more granularity. • Scenario 9: Localizing ontological resources. Most of the implemented ontologies are available in English, therefore, one big issue for non-English speakers to be able to understand the resultant ontology well is to have the output in their own language. In this way, the best-fit ontology founded/implemented by ontology developer should be translated to the respected language. NeOn scenarios can follow two life cycle models, either a waterfall model, which is famous in software engineering including initiation, design, implementation, and maintenance, or iterative-incremental model (Royce 1970). The latter model defines numbers of iteration to provide the final version of the resultant ontology. Besides the specific processes and activities (i.e. specification, conceptualization, formalization, reuse, reengineering, merging, restructuring, localization, and implementation), all the aforementioned scenarios include support activities, namely, knowledge acquisition, documentation, configuration management, evaluation, and assessment.	
Human-Centered Ontology Engineering Methodology (HCOME) discusses the importance of involvement of knowledge workers, besides, knowledge engineers to develop and evolve the resultant ontology. HCOME encompasses of three phases; i) Specification to	(Kotis and Vouros 2006)

Abstract	**Source**
define aim, scope, requirement and team, ii) Conceptualization to acquire knowledge, develop and maintain ontology and finally iii) Exploitation to use and evaluate ontology. Within the first phase of the ontology life cycle, the knowledge workers and ontology engineers should work collaboratively to identify a common way. To support HCOME, Human-Centered Ontology Engineering Environment (HCONE) provides a tool for knowledge workers to interact directly with their team. HCONE identifies three spaces to store the developed ontology; i) Personal Space where the ontology developed by a person is stored, ii) Shared Space where the other co-workers have access to the ontologies and may send their comments to the developer(s) of the ontology, and iii) Agreed Space, where the ontology agreed by the development team, is stored.	
Distributed Engineering of Ontologies (DILIGENT) Methodology focuses on decentralization, partial autonomy, iteration and non-expert builders for developing an ontology that is neglected by the other methodology of ontology engineering (Pinto, Tempich and Staab 2009). However, it borrows the core from On-To-Knowledge. Ontology engineer(s), knowledge engineer(s), a domain expert(s) and ontology user(s) shaping a board and are directly involved in the DILIGENT process to build ontology regardless of their location. DILIGENT introduces two versions of ontologies; one is the shared ontology, which is available to all users but evolved just by the board. The board creates the shared ontology and is responsible for evolving process, while, the end-users may change the shared ontology based on their needs and provide a localized ontology (Pinto, Tempich and Staab 2009). DILIGENT composes five steps: • Build: build up a small team involved Ontology engineer(s), knowledge engineer(s) and domain expert(s) to create a shared ontology, which is not required to be complete. • Local adoption: the users adapt a copy of the shared ontology based on their own needs in their local environments. The outcome of this step is a localized ontology. • Analysis: the board selects which changes go to the next version of the ontology based on the frequency and volume of changes to the local ontologies. The outcome of this step is a list of changes that were agreed by the board. • Revision: the domain experts decide whether the changes should be applied and the ontology engineers from the board formalize and finally implement the new version of the ontology. The outcome of this step is the new version of the shared ontology. • Local update: if the users wish to align their local ontologies with the new version of the ontology, they apply the changes for the local one. This step is close to the second step.	(Pinto, Tempich and Staab 2009)

Abstract	**Source**
The Unified Process for ONtology (UPON) methodology was built based on the premises of the Unified Process (Jacobson, Booch and Rumbaugh 1999). UPON is a use-case driven methodology rather than a set of methods for building generic domain ontologies (Antonio, Missikoff and Navigli 2009). UPON consists of cycles, phases, iteration, and workflow. Each cycle has four phases: • Inception phase to capture requirements and conceptual analysis, • Elaboration phase to identify and structure fundamental concepts, • Construction phase to design and implement the ontology, and • Transition phase to test the ontology. Each phase can have an iterative workflow, including requirements, analysis, design, implementation, and test but the focus on each workflow is different depending on the respective phase (e.g. in the inspection phase the focus is on requirements). When a cycle is completed, a new version of the ontology, which is more completed and enriched than the previous version, is provided. Multiple iterations of the workflow may be needed to complete each of the phases entirely. The UPON consists of five workflows as follows: 1. Requirement to specify the needs and user's point of view by i) determining the scope, ii) defining the purpose, motivating scenario and objectives of creating the ontology, iii) writing a storyboard(s) by the domain expert, iv) creating application lexicon, v) identifying competence questions, and vi) identifying and prioritizing use-case(s) 2. Analysis to refine and structure the requirements, which are identified in the former workflow. This workflow consists of four building blocks as follows: i) Acquiring domain resources and building a domain, ii) Building the reference lexicon based on the application and domain lexicons, iii) Modeling the application scenario using UML, and iv) Building the reference glossary based on the reference lexicon. 3. Design to formalize the reference glossary in an ontological structure. This workflow consists of i) modeling concepts, and ii) modeling concept hierarchies and domain-specific relationships. 4. Implementation to encode the informal (designed) ontology to a formal (coded) ontology. 5. Test to evaluate the syntactic, semantic and social (user) quality of the implemented ontology.	(Antonio, Missikoff and Navigli 2009)

Abstract	**Source**
Knowledge/ontology engineer(s) should be involved in performing design and implementation workflows, and domain expert in providing requirements and analysis. Both KE and DE are needed for testing the usability and functionality of the implemented ontology.	
The On-To-Knowledge is a generic ontology engineering methodology, which distinguishes between “Knowledge Meta Process” and “Knowledge Process”. The first process addresses developing a new ontology-based system, and the second one addresses managing and using the developed ontology. On-To-Knowledge, however, focuses on Knowledge Meta Process as the core process of ontology engineering. The Knowledge Meta Process includes five main phases: • Feasibility study phase to identify the problem and potential solutions. The outcome of this phase is CommonKADS worksheets. • Kick-off phase to clarify what this ontology should support and sketch the planned area of the ontology. The outcome of this phase is requirement specification document and a semi-formal description of the ontology. • Refinement phase to formalize a refined semi-ontology into the target ontology through generalization and/or specialization of the concepts and the relation by applying the top-down, bottom-up or middle-out approach. The outcome of this phase is the target ontology, which meets the requirement specified in the previous phase. • Evaluation phase to evaluate the ontology from the perspective of technology (i.e. syntax, semantic, interoperability scalability, etc.), users (i.e. satisfaction by the result), and end-product (i.e. clean up the ontology from common modeling error). The outcome of this phase is an evaluated ontology; however, it may roll out after several iterations of evaluating and consequently refining. This iteration will be stopped whenever evaluation criteria are met. • Evolution phase to apply changes, switch-over to a new version of the ontology, and keep the ontology updated. At the beginning of this phase three questions of “who is responsible for maintenance?”, “how the evolution is performed?” and “in which time intervals is the ontology maintained?” should be clarified. The outcome of this phase is an evolved ontology.	(Sure, Staab and Studer 2009)
METHONTOLOGY incorporated a methodology, which was developed through the management, development, and support activities. The management activates include planning, control, and quality assurance. The development activities include: • Specification activity, which identifies the purpose of the ontology, including the goal of use, scenarios of use and end-users, the level of formality (i.e. informal, semi-informal, semi-formal and formal), and scope of the use.	(Fernández-López, Gómez-Pérez and Juristo 1997)

Abstract	Source
• Conceptualization activity, which identifies "a conceptual model that describes in terms of the domain vocabulary identified in the ontology specification activity". In this stage, the glossary of the terms, which are grouped as nouns and verbs, is defined based on the specification document provided in the previous activity. • Formalization and implementation activities, which transform the conceptual model into the formal and computable language. Besides the development and management activities, the support activities will facilitate ontology development. The workload of the support activities, however, depends on the state of the development activities. The support activities include: 1. Knowledge Acquisition, which identifies the knowledge sources (e.g. books, experts), and defines how the respected knowledge should be extracted with respect to the type of sources. This activity will be mostly done after the specification and within conceptualization. 2. Integration, which defines how an existing ontology will be reused or integrated to have a new ontology. This activity will be done before implementation activity if needed. 3. Evaluation, which verifies the correctness of the ontology and validates the process of developing the ontology. 4. Documentation, which details all phases, results, limitation, and challenges faced with them through developing the ontology. 5. Configuration Management, which records and controls the changes.	
This methodology is based on the TOVE (TOronto Virtual Enterprise) project, which has four steps: • Providing a Motivating Scenario in a form of the story problems or examples. The Motivating Scenario may be presented by the end-user(s) of the intended application(s), and it also brings some solution to the scenario problems. • Defining the Informal Competence Questions based on a set of queries of the Motivating Scenario. The Informal Competency Questions should be defined hierarchically means the higher-level questions need the solution of lower level questions. • Defining the Terminology of the new or extended ontology to specify the concepts and properties of the domain of interest. • Defining the Formal Competency Questions to determine if the questions are consistent with the union of the set of axioms in the proposed ontology and a set of instances. The axioms should also be defined to characterize the solution to the questions.	(Grüninger and Fox 1995)

Abstract	Source
Evaluating whether the proposed ontology is consistency and entailed the competence questions.	
This methodology includes four stages: • Identify the purpose and the scope; the answers of the following questions are identified the scope of the work: "Why the ontology is being built?", "What its intended uses", and "Who is the intended user of the ontology?" (i.e possible answer can be: small or large group), and "What is the characteristics of the range of intended user of the ontology?" (i.e. possible answer can be: for a specific application or part of a knowledge-base). • Building the ontology consists of three phases; i) capture the concepts and relationships in the domain of interest (i.e. scoping) focusing more on the knowledge level than coding language, ii) coding the conceptualization captured in the previous phase in a formal language, and iii) integrating existing ontologies, if there is any. • Evaluation of the implemented ontology with respect to the requirements specifications, competency questions, and requirements taken from the real world. • Documentation of all important assumptions, both formal and informal discussion within developing phases	(Uschold and King 1995).

11.2 Nursing Task, KSC and Learning Unit

Table 23 represents the nursing tasks identified by KldB-2011, the tasks are translated into English by author.

Table 23 Nursing Tasks identified by (Bundesagentur für Arbeit, 2011)

KldB-ID	Task
KldB -T-a	Work with medical professionals and assist with medical procedures, e.g. Clean miracles and attach medical bandages
KldB -T-b	Measures of treatment care and special care in accordance with established care plans to carry out, for example, Administer medicines, administer infusions, provide wounds
KldB -T-c	Prepare patients and patients for diagnostic, therapeutic and operative measures and take care of such measures
KldB -T-d	Monitor the health of patients and their response to treatments
KldB -T-e	Record treatments and update regularly the information on the health of patient
KldB -T-f	Support individual patients in the organization and planning of care measures
KldB -T-g	Assist in emergencies during first aid procedures

Table 24 points the nursing KSC, which is defined by (KrPfAPrV 2003) and (Oelke 2003)

Table 24 Nursing KSC identified by (KrPfAPrV, 2003) and (Oelke, Uta;, 2003)

Learning Outcome	ID	Sub-concept
Knowledge	KSC_1	Knowledge of health and nursing, health and child care, and care and health sciences (KPf)
	KSC_2	Care Relevant knowledge of the natural sciences and medicine (KNaMe)
	KSC_3	Care Relevant knowledge of the humanities and social sciences (KSo)
	KSC_4	Care Relevant knowledge of law, politics, and economics (KRePoWi)
Skill	KSC_5	Recognizing, Assessing and Evaluating Care Situations for People of All Age Groups (PfMeErkErfBe)
	KSC_6	Selecting, carrying out and evaluating care measures (PfAsDuAus)

	KSC_7	Maintaining personal care (PfPeAu)
	KSC_8	Fostering care treatment in nursing science (PfWiErAu)
	KSC_9	Establishing life-sustaining emergency measures until the physician arrives (LeAninAr)
	KSC_{10}	Developing professional self-awareness and learning to cope with professional requirements (BeSeEnLeBeAn)
Competence	KSC_{11}	Providing support, advice, and guidance on health and care-related issues (UnBeAnPf)
	KSC_{12}	Contributing to the development and implementation of rehabilitation concepts and integrate these into the nursing care (EnUmRePfIn)
	KSC_{13}	Organizing quality criteria, legal frameworks and economic and ecological principles (PfQuReRaWiOkAu)
	KSC_{14}	Participating in medical diagnostics and therapy (MeDiThMw)
	KSC_{15}	Influencing the development of the nursing profession in the societal context (EnPfb)
	KSC_{16}	Working together in groups and teams (GTZuAr)

Refers to the directive 2005/36/EC of the European Parliament, the nursing education should be taught in two main parts of theoretical and clinical and then each part is sub-divided into the detailed parts. Table 25 elaborates the main parts.

Table 25 Nursing Learning Areas identified by EC

A. Theoretical instruction		
a. Nursing	Nature and ethics of the profession	
	General principles of health and nursing	
	Nursing principles in relation to:	• General and specialized medicine • General and specialized surgery • Child care and pediatrics • Maternity care • Mental health and psychiatry • Care of the old and Geriatrics
b. Basic sciences	Anatomy and physiology	
	Pathology	

A. Theoretical instruction		
	Bacteriology, virology, and parasitology	
	Biophysics, biochemistry, and radiology	
	Dietetics	
	Hygiene:	• Preventive medicine • Health education • Pharmacology
c. Social sciences	Sociology	
	Psychology	
	Principles of administration	
	Principles of teaching	
	Social and health legislation	
	Legal aspects of nursing	
B. Clinical instruction		
Nursing in relation to:	General and specialized medicine	
	General and specialized surgery	
	Child care and pediatrics	
	Maternity care	
	Mental health and psychiatry	
	Care of the old and Geriatrics	
	Home nursing	