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An Ontology-Based Approach for the Semantic Representation of Job Knowledge

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ABSTRACT The essential and significant components of one's job performance, such as facts, principles, and concepts are considered as job knowledge. This paper provides a framework for forging links between the knowledge, skills, and abilities taught in vocational education and training (VET) and competence prerequisites of jobs. Specifically, the study is aimed at creating an ontology for the semantic representation of that which is taught in the VET, that which is required on the job, and how the two are related. In particular, the creation of a job knowledge (Job-Know) ontology, which represents task and knowledge domains, and the relation between these two domains is discussed. Deploying the Job-Know ontology facilitates bridging job and knowledge elements collected from various sources (such as job descriptions), the identification of knowledge shortages and the determination of mismatches between the task and the knowledge domains that, in a broader perspective, facilitate the bridging requirements of labor market and education systems.

INDEX TERMS Job knowledge, job performance, vocational education and training, ontology development.

I. INTRODUCTION

A practitioner typically qualifies him or herself by practicing a learned profession, and participating in (continuous) vocational education and training (VET). The European Center for the development of vocational training defined VET as "education and training which aims to equip people with knowledge, know-how, skills and/or competences required in particular occupations or more broadly on the labor market" [17]. There are relations between the job requirements and obtained competences in the world of work [38]. Most European countries today are utilizing and applying competence-based approaches to comply with the needs of the labor market [40]. The job applicant, hence, should be able to demonstrate knowledge, skills, and abilities (KSAs) that are required to fill job vacancies [14]. This is not limited to the pre-employment (job applicant/seeker) phase, but also applies to the employment (job holder) phase in which one typically aims to stay employed and grows into higher positions. On the one hand job applicants or holders should continuously improve their competences with respect to market demands in order to stay employable. On the other hand organizations (job owners), recruit applicants with a portfolio of required KSAs. They need competent employees who are able to perform their core tasks in a reliable manner over time. In the competitive marketplace, the mutual interest of both organizations and their (prospective) employees is to preserve and/or enhance KSAs. The former is likely to be exhibited through the deployment and continuous improvement of human resources (HR) practices, whereas the latter through personal profile development by means of lifelong learning [67]. According to the definition of the European Commission, *competence* is "the proven ability to use knowledge, skills and personal, social/methodological abilities, in work or study situations and in professional and personal development" [18]. Work-based competences can be categorized into three groups: competences defined in terms of (i) a list of tasks, (ii) a collection of attributes, and

(iii) a holistic or integrated relationship [27]. More broadly speaking, *meta-competence* is concerned with two key issues, firstly, "how to apply skills and knowledge in various task situations", and secondly, "how to acquire missing competences" [49]. Since job knowledge is one of the strongest predictors of job performance [12], and since competence can be conceptualized as (disaggregated) job performance [47], knowledge is one of the key drivers of job specific competence [47]. For the purpose of this article we define job knowledge as "the learned facts, principles, concepts and other pieces of information that are considered important in the performance of one's job" [12].

This study provides a framework for making the links between the KSA taught in VET and the competence prerequisites of jobs. That is, the study is aimed at creating an ontology for the semantic representation of "that which is taught in VET", "that which is required on the job" and "how the two are related".

Recent studies show that ontologies are widely considered to be an appropriate knowledge representation technology [5], [10], [22], [50], [54], [68] for the specification of a shared conceptualization [26] and machine readable format [25].

This study uses a hybrid approach and employs existing methodologies to develop a solution to semantically represent job knowledge. In doing so existing ontology development methodologies are drawn upon such as Enterprise Ontology [63], TOVE [24], METHONTOLOGY [21], CommonKADS [53], On-To-Knowledge [58] and NeOn [57] which all provide guidance for creating and maintaining ontologies.

In the HR context different ontologies have been developed for representing the relation between job, employee and competence [2], [4], [6], [48], [50]; however there is little systematic effort at bridging VET outcomes to labor market needs [34], [37].

This article presents a framework for creating a job knowledge ontology. This ontology, named the *Job-Know* ontology, may be employed to represent both the task and knowledge domains of a particular job, and the relation between these two domains. Section 2 consists of three parts; firstly it discusses the terminology and relations between knowledge, competence and task, secondly ontology development methodologies and thirdly it summarizes the related work from the perspective of competence-based ontologies. Section 3 provides the framework for creating the *Job-Know* ontology. Specifically, it discusses how the NeOn methodology is utilized and customized to create the *Job-Know* ontology. Section 4 explains the conceptualization and formalization of the *Job-Know* ontology based on the results of two EU funded projects, namely Med-Assess[1] and Pro-Nursing.[2] Section 5, finally, concludes the paper and discusses the as of yet unresolved issues and offers suggestions for future work.

[1] Med-Assess – Adaptive Medical Profession Assessor, Official website, http://www.med-assess.eu

[2] Pro-Nursing - Professional Nursing Education and Training, Official website, http://www.pro-nursing.eu

II. RELATED WORKS

A. FRAMEWORKS AND STANDARDS FOR DEFINING KNOWLEDGE, COMPETENCE AND TASK

Refers to the European definition, the qualification process is based on learning outcomes (i.e. outcome orientation) [18]. It reflects the knowledge, skills and competences that a learner should obtain within the process of learning [18]. Regardless of general or vocational education [62], a learner in a specific field of work or study should learn "knowledge" i.e., a "body of facts, principles, theories and practices" [18]. However, obtaining knowledge exclusively cannot enable the learners to apply it in practice. The ability that enables the learner to "apply knowledge" and "use know-how" to perform tasks is understood as "skill" [18]. Although ability and readiness of the learner to apply knowledge is crucial, it is not sufficient. "Competence" as the proven ability to use knowledge and skill is definitively needed [18]. Taking the definition of the European Qualification Framework (EQF) into account, there are similarities between the three categories of knowledge, skill and competence, since "competence" includes skills and "skill" contains specific "knowledge" [19]. In the DQR matrix defined by the German Qualification Framework (known by its German abbreviation DQR), competence refers to both "professional" and "personal" competences and consequently, "professional competence" is subdivided in "knowledge" and "skill" [23]. In this way "professional competence" encompasses both knowledge and skill.

The European Skills/Competences, qualifications and Occupations (ESCO) establishes a triangular linkage between occupations, skills/competences, and qualifications [20]. ESCO aims at matching job seekers to the skills and competences required for performing a job across Europe [20]. ESCO utilized standards such as International Standard Classification of Occupations (ISCO),[3] EQF, Fields of Education and Training (FoET)[4] and Statistical Classification of Economic Activities in the European Community (NACE)[5] for developing a multilingual and shared understanding of these three pillars [37].

ISCO-08 provides a system for classifying all occupations and also defines four skill levels (i.e. (i) primary, (ii) lower-/upper-/post-secondary, (iii) first stage tertiary (short or medium duration), and (iv) first stage tertiary (medium duration) or second stage tertiary), based on three attributes: (i) the characteristic tasks which should be performed, (ii) the type of skill required for performing the tasks, and (iii) the typical occupations [28]. At each level the formal education requirement(s) is/are also defined by

[3] http://www.ilo.org/public/english/bureau/stat/isco

[4] http://www.uis.unesco.org/Education

[5] http://ec.europa.eu/eurostat/web/nace-rev2

using the International Standard Classification of Education (ISCED) [62]. ISCO therewith defines the relation between occupations, skill levels, and education requirements.

In summary, learning outcomes enable job holders to perform their required tasks within the job context. There are remarkable International, European, and national classification systems, such as ESCO [20] and ISCO [28], for occupations, skills, and education, which lie at the basis of this study.

Moreover, a job is defined as a list of tasks or piece of the work. *Task* is consequently defined as clusters of activities or sequences of related activities directed at specified objectives. Tasks are a quite detailed way of describing work and include certain attributes such as an action verb, the object of the action, the source of information or instruction, and the results [46], [65].

B. ONTOLOGY DEVELOPMENT METHODOLOGIES

Today, several ontology development methodologies exist for assisting ontology engineers and domain experts to create, reuse, and maintain their ontologies.

The first reviewed methodology built for ontology development is the Enterprise Ontology [63], which comprises four stages (i) *identify the purpose and the scope* (i.e. determining why the ontology is wanted and decide how formal the ontology needs to be) (ii) *building the ontology* (i.e. keeping clarity, consistency and coherence, extensibility and reusability within *capturing*, *coding*, and *integrating existing ontologies)*, (iii) *evaluation* (i.e. manually checking whether or not the ontology is able to answer the formal competency questions), and (iv) *documentation* (i.e. establishing a guideline for documenting the developed ontology) [63].

The TOVE (TOronto Virtual Enterprise) project introduced its methodology in four steps, (1) defining the competence of the ontology, (2) defining the terminology of the ontology, (3) specifying the definition and constraints of the terminology and (4) testing the competence of the ontology [24].

METHONTOLOGY incorporates a methodology which is developed through the implementation of six main steps, namely, (1) *specification*: identify the purpose of the ontology, (2) *conceptualization*: identify concepts, instances, relations, (3) *formalization*: give a structure to the acquired knowledge, (4) *integration*: find out the resources and/or reuse of existing ontologies, (5) *implementation*: codify the ontology model in a formal language and (6) *maintenance.* Besides the main steps, three support activities are also defined, namely (i) *acquiring knowledge*: non-structured/ structured interviews, informal/ formal text analysis, (ii) *documentation*: document not only the code of the ontology but also all the relevant documents, and (iii) *evaluation*: verification and validation of the ontology, respectively, for guaranteeing the correctness of the ontology and the process of developing it [21]. METHONTOLOGY allows the ontology developers to improve the developed ontology iteratively by applying the *maintenance* step (i.e. step 6) [21].

The UPON (Unified Process for ONtology) methodology [11] which was built based on the premises of the Unified Process [29]. UPON is a use-case driven methodology rather than a set of methods for building generic domain ontologies [11]. UPON consists of cycles, phases, iteration, and workflow. Each cycle has four phases, (1) *inception*: capture requirements and conceptual analysis, (2) *elaboration*: identify and structure fundamental concepts, (3) *construction*: design and implementation of the ontology, and (4) *transition*: test the ontology. Each phase can have an iterative workflow (*requirements, analysis, design, implementation,* and *test*) but the focus on each workflow depends 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 is provided [11]. At times multiple iterations of the workflow may be needed to complete each of the phases entirely [11].

CommonKADS is a methodology for building knowledge based systems which aims to be a generic reference model for knowledge based planning tasks [53]. CommonKADS has a modular development principle and emphasizes conducting an early feasibility study and the redesign and the reuse of ontologies [53]. CommonKADS determined two kinds of mapping methods; (i) no change or (ii) a change in the semantics of the mapped ontology [30].

The On-To-Knowledge methodology includes five main phases, (1) *feasibility study*: to identify the problem, (2) *kickoff*: to clarify what this ontology should support, (3) *refinement*: to formalize a refined semi-ontology into the target ontology, (4) *evaluation*: to evaluate technology, users, and ontology to become ready for the rollout and (5) *evolution*: to manage evolution and maintenance [58]. In the third, fourth and fifth phases, it is possible to go back iteratively and improve the ontology [58].

The NeOn methodology includes a glossary, a set of nine scenarios, two ontology network life cycle models and a set of guidelines [57]. The nine NeOn scenarios are flexible for collaboratively building ontologies because of their emphasis on reusing and re-engineering existing resources [57]:

- Scenario 1: From specification to implementation: building the ontology from scratch without reusing knowledge resources. This scenario is the basis of the methodology and should be combined with the other the scenarios. It includes *specification*, *conceptualization*, *formalization* and *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.

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- Scenario 7: *Reusing* ontology design patterns (ODPs).
- Scenario 8: *Restructuring* ontological resources.
- Scenario 9: *Localizing* ontological resources.

After providing the ontology specification requirement document in specification phase, refers to the type of the knowledge resources, ontological and/or non-ontological resources one or more scenarios will be selected and followed; however the scenario 1 is considered as the basis and regardless of selecting which scenario(s), it will be followed.

Besides the specific processes and activities (i.e. *specification, conceptualization, formalization, reuse, reengineering, merging, restructuring, localization and implementation*), all the scenarios include support activities, namely, *knowledge acquisition*, *documentation*, *configuration management*, *evaluation*, and *assessment* [57].

As a result, although there are some differences between the aforementioned methodologies, they also have clear similarities. Firstly, each one of them stresses the start point and recommends a thorough feasibility study, kickoff, identification of the purpose, specification and well defined competency questions [1], [30]. Secondly, and rather than starting from scratch, each 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 [30]. Most of them present maintenance and evolution of the ontology as the final phase, which encompasses an iterative process.

Based on a literature study of ontology development methodologies, the authors found that scenario-based methodology of NeOn is easy to use, especially with regard to publishing practical and detailed guidance for each scenario. The NeOn methodology defined a specific glossary. Therefore the definition of each activity (e.g. merging, reusing) is clearly determined for the ontology engineer. This glossary prevents misunderstandings of the functional words by the ontology developing team includes domain expert, end-user, ontology engineer and knowledge engineer. Furthermore, Neon focuses on reuse of the knowledge resources which are subdivided into ontological and non-ontological recourses. This way, the ontology engineer has a clear understanding to work on both resources. Moreover NeOn provides a practical guideline for the dynamic evolution of the ontology. In this article, the authors used the combination of aforementioned scenarios of the NeOn methodology for developing the *Job-Know* ontology; however the scenarios are tailored based on the needs. This part is discussed in section 3.

C. JOB KNOWLEDGE ONTOLOGIES

In the context of HR, different ontologies have been developed for representing the relation between job, employee and competence:

- The HR ontology in [2] is derived from the KOWIEN ontology [2]. This ontology is divided in seven sub-ontologies; *skills, person, organization, industry, job posting, job application* and *education*. This ontology is developed for supporting recruitment processes [2]. The authors, however, did not discuss the education sub-ontology in detail.
- The skill ontology in [4] mainly defines the relations between *employee*, *skill instance*, *position* and *position skill requirement*. In this ontology *position skill requirement* connects *position* to *skill instance*; however, the authors did not address how *position skill requirement* could be addressed through education.
- A professional learning ontology is developed in [52] with the aim of representing a common understanding of competence in HR [52]. The *LearningOpportunity* concept has a relation with *InstructionalEntity*, which includes two sub-concepts, namely *training* object and *learning* object. This main concept has a "*prerequisite*" relation with *competency* [52]. *OrganizationalEntity* consists of *task*, *process*, *department* and *role*. It has a "*requires*" relation with *competency* [52].
- The aim of the research appeared in [15] is integrating competency management with e-learning and other human resource functions. The competence ontology in [15] defines that *job has skill* and *skill is related* to *learningObject*.
- The LIP project focused on managing learning in an organizational context, which can be traditional courses and/or learning objects as well as colleagues or experts' experiences [51].
- An ontology-based competency formalization approach is developed by [48] as a way of representing competency-related information in an ontology together with other metadata, in order to enhance machine automation in resources retrieval. In this approach, learning objects are annotated with instances of competency is specified in a Competency Class. The Competency Class is represented by means of three major classes: *competency definition, proficiency level, and knowledge reference*.
- In [42] ontologies were used to classify available human resources. An HR ontology was created with several sub-ontologies based on the HR-XML standard. Competencies were represented in the *skills* sub-ontology. These competencies provided the basis for job-requirement and employee skills descriptions. Levels of particular competencies were also handled within this sub-ontology. "*Person*" and "*Organization*" sub-ontologies described 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.

Each one of the aforementioned ontologies considers the relation between learning, competence and job. However, they all are mainly focused on the side of the labor market and the learning objects are mostly considered in light of on-the-job training.

III. JOB-KNOW ONTOLOGY

This paper discusses the *Job-Know* ontology which aims to connect the competence demand on the labor market to KSA taught in VET so as to facilitate an analysis of gaps and mismatches of KSAs and tasks in not only VET but also the labor market.

A. SEMANTICS APPROACH

From the educational side, practitioners need to learn particular KSAs to obtain the competences that enable them to perform specific tasks within a job. From the labor market perspective, employees should perform defined tasks in a specific job by drawing upon their obtained competences. VET trains practitioners and provides them with KSAs that are required on the labor market.

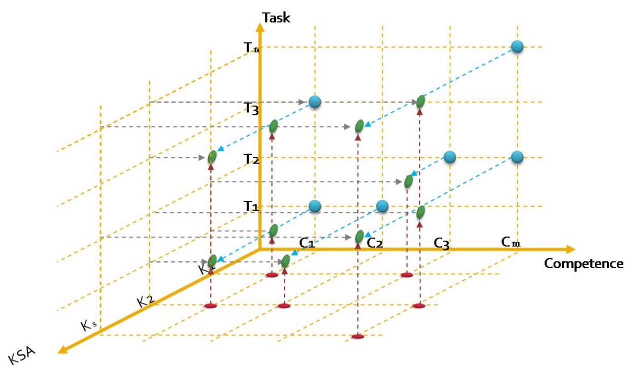

FIGURE 1. **TCK 3-D association of the Job-Know ontology.**

Performing a task requires competence(s) and obtaining competence is rooted in the acquisition of specific KSAs. Figure 1 illustrates the 3-Dimensional semantic relation between Task, Competence, and Knowledge (including skill and ability) i.e. *TCK 3-D*.

For example, employees should have *Competences 1* and *2* to be able to perform *Task 1* and, consequently, they should (have to) obtain *KSA 1* and *2*. Figure 1 depicts the association between KSAs which are needed to perform certain task(s). The *TCK* 3-D space provides the opportunity to clarify the competences that are needed and the competences that are taught from the perspective of the labor market and VET, respectively.

This *TCK* 3-D space can provide answers to the following questions:

- How are tasks matched with KSAs?
- Which KSAs are essential to task performance?
- Which KSAs are unimportant to performing the job and have a weak connection?
- Are there any existing KSAs for new competence(s) and/or task(s) or new KSAs are needed for new competence(s) and/or task(s)?

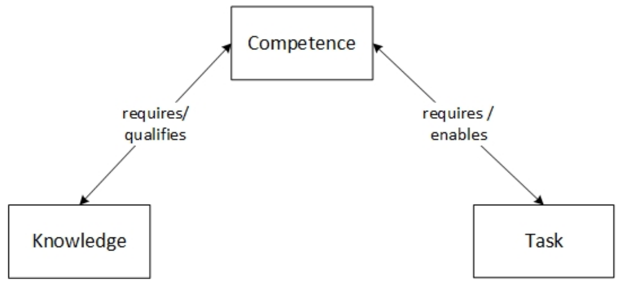

FIGURE 2. **Meta-model of the Job-Know ontology.**

Based on the *TCK* 3-D spaces, the *Job-Know* ontology is formalized for conceptualizing the task and knowledge domains. Figure 2 shows the meta-model of the *Job-Know* ontology.

The *knowledge domain* provides a formalization of the relation between concepts/terms in the knowledge domain which should be taught in VET.

The *task domain* provides a formalization of the concepts/terms of the tasks which should be performed by the employee.

The meta-model consists of three main concepts and two relations as discussed in further detail below:

- Task *requires* Competence
- Competence *enables* Task
- KSAs *qualify* Competence
- Competence *requires* KSAs

Here, the consequent reason from the relation between task, competence and KSA is:

- If Task X *requires* Competence Y and Competence Y *requires* KSA Z
    - Then Task X *requires* KSA Z
- If KSA A *qualifies* Competence B and Competence B *enables* Task C
    - Then KSA A *is a qualified enabler for* Task C

In this way, the framework creates the relation between task and KSA and in a global view provides the list of knowledge domains needed for performing the job and thus gives meaning to the term "job knowledge".

B. METHODOLOGY OF DEVELOPING JOB-KNOW ONTOLOGY

The *Job-Know* ontology is developed to identify the relation between KSA, which is acquired in VET, and tasks, which are defined in a job. Based on the study of the ontology development methodologies in section 2, for developing *Job-Know* ontology, a hybrid approach was defined focused specifically on the NeOn methodology.

Figure 3 shows an adapted approach for developing the *Job-Know* ontology. The four phases are defined based on the first NeOn scenario:

- *Specification:* in this phase an ontology requirements specification document is provided. This document

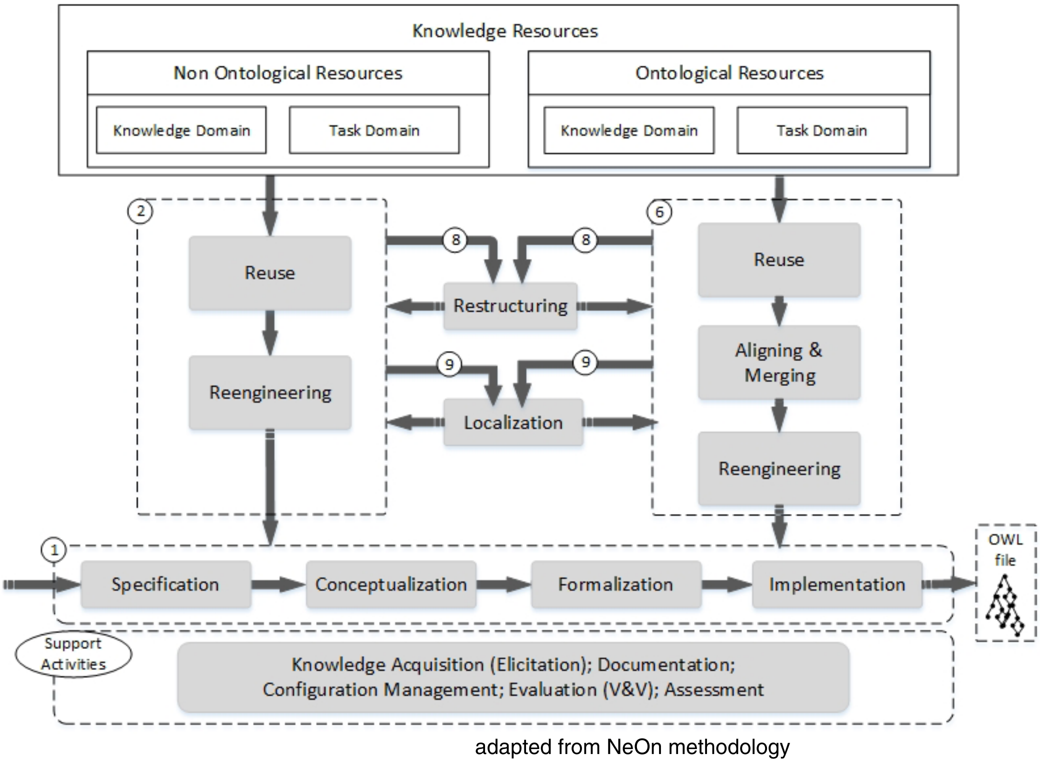

FIGURE 3. Job-Know - Framework for creating job knowledge ontology adapted from NeOn methodology.

states that the *Job-Know* ontology is developed for bridging between VET and the labor market and replies to the questions which are mentioned in the previous section. In this stage the job and respective VET program are studied [8], [9], [16], [28], [62].

- *Conceptualization:* within this phase, candidate knowledge resources are identified. As shown in Figure 2, the *Job-Know* ontology is built on two domains; *knowledge*, which is acquired in VET, and *task*, which is nested in a job based on the labor market requirements. These two domains include non-ontological and ontological knowledge resources. The knowledge domain consists of facts, principles and concepts [7]. From the perspective of education, this domain can be considered in a curriculum form, which is a kind of taxonomy. The task domain is formalized based on process modeling of a job and systematic job analysis. In addition the relation between VET and job via competence should be taken into account. With respect to candidate knowledge resources, different NeOn scenarios can be selected (see below).
- *Formalization:* after conceptualization of the knowledge and task domains and the relation between them, the *Job-Know* domain should be formalized into a semi-computable model.
- *Implementation:* The formalized *Job-Know* domain is implemented in OWL (a Web Ontology Language). In this work the STUDIO[6] system is used for the implementation.

After the specification, for conceptualizing, formalizing and finally implementing the *Job-Know* ontology, scenarios two, six, eight and nine from the NeOn methodology are used, which are explained in greater detail in section 4 in the context of nursing as a use-case.

IV. USE CASE: NURSING JOB-KNOW ONTOLOGY

Nursing is a highly standardized profession which requires high qualification [61], [67]. ''Improving the mobility of workers and students is one of the top priorities among policy initiatives in the European Union'' [61]. Nurses should keep their competences continuously up-to-date to be able to deliver high quality and cost-effective care [39]. Continuous education to provide demanded competences is taken into account by individual nurses and the health care sector. 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. Sometimes nurses complain that the healthcare sector does not have a system to figure out their learning needs for improving their competences [66].

[6]STUDIO – Ontology Driven Learning Environment, Official homepage of STUDIO: http://corvinno.com/web.nsf/do?open&lang=en&page=proj-studio#

Nursing professionals are named with different titles containing the word ''nurse'' or ''nursing'' such as ''nursing sister'', ''registered nurse'', ''charge nurse'' and so on [28]. Since the use-case discussed in this part of the article is based on the results of Med-Assess and Pro-Nursing projects, and the focus of these two projects are on basic nursing in Germany, therefore this part of the research focuses on ''Gesundheits- und Krankenpfleger/in'' which refers to the classification of German national occupations classification (known by its German abbreviation KldB) with the KldB code of 81302 [8], [9]. KldB maps this occupation as ''nursing associate professionals'' with ISCO-08 Unit Group of 3221 which is categorized under sub-major group of ''health associate professionals'' and the major group of ''technicians and associate professionals'' [28]. The Nursing associate professionals (Unit Group 3221) provide basic nursing tasks and consequently the job holder should work under supervision or support of an expert in the health field. In spite of nursing associate professionals, Nursing professionals (Unit Group 2221) are responsible for planning and management of patients care autonomously or in teams [28]. Nursing professionals can be considered specialists in the field in Germany [8]. Although the nursing tasks performed may vary between countries and also within the states of a country [28].

The ISCO skill levels starts at skill level one with simple and routine physical or manual tasks such as cleaning workers, which need the first stage of the basic education [28]. Skill level two includes the ability to read information, perform operating machinery, electronic equipment, and so on. For this level the practitioner needs to obtain at the first stage of secondary education and moreover vocation-specific education can be requested, depends on the type of the occupation such as cooks [28]. Skill level three involves complex technical and practical tasks that support the job holders in obtaining factual, technical, and procedural knowledge in their field, such as general nursing in Germany [28] which is the target of this study. Skill level four includes the tasks which have roots in complex problem-solving, decision-making and creativity; thus the job holder should hold high level and excellent communication skills and obtain a first degree or higher qualification such as is the case for specialized nursing [28].

From a European perspective, this is especially interesting, as different countries run different educational programs for their nurses, thus inevitably resulting in different competence levels [33]. Prior to assessing competences and identifying competence gaps, it is essential to determine the relation between task and competence i.e. what competence(s) is/are required for performing a certain task [33]. Nursing tasks can be modeled in reference to the care processes, thus identifying all performed nursing actions. The nursing tasks should be analyzed and later mapped to appropriate KSA. Developing a domain ontology for formalizing nursing knowledge was one of the objectives of the Med-Assess project [32], [34], [44] and expanding this ontology and adding the task domain to this core is the objective of its successor, the Pro-Nursing project. In the following, the conceptualization and formalization of knowledge and task domains are discussed.

A. TASK DOMAIN

Generally, to extract the existing non-ontological resource of German nursing tasks, the authors used the German Care Council (known with its German abbreviation DPR)[7] [13], Nursing Act (known with its German abbreviation KrPflG)[8] [36], a special administrative law in the scope of the Federal Republic of Germany. The details of this part are discussed by the authors in [32].

In order to populate the *Job-Know* ontology, the technique of process modeling is employed. Since the quality of the input of the ontology is critical to our approach, the processes themselves were defined in terms of individual level tasks, which were then validated (i.e. compared and contrasted), against tasks that were independently derived through a systematic nursing job analysis. In this way an adequate and accurate sampling of the underlying nursing task domain was ensured. The final list of processes was then used to populate the task domain of the *Job-Know* ontology. Below systematic job analysis and the process modeling are described in greater detail.

Our systematic job analysis uses three different sources to identify nursing tasks. Specifically, the job analysis focused on vacancy data, interview data, and observational data. Since the authors focused on tasks for this part of the endeavor, only known work-oriented methods for job analysis were eligible (as opposed to worker-oriented methods). The former include task inventories, functional job analysis (FJA), and the critical incident technique (CIT) [7]. Task inventories are listings of all work activities, formulated as tasks, performed to complete one or more jobs [7]. FJA also describes what workers do, but in relation to one of the three aspects of work, namely *Data*, *People*, and *Things* [7]. The CIT, finally, focuses on the recall of specific instances of worker behavior, either outstanding or unacceptable, on the job [7].

With a more detailed level of tasks than FJA and a less situation specific approach than CIT, the task inventory method meets the goldilocks principle of being just right in level of detail [7]. The method of choice for collecting task data is therefore a task inventory. Specifically, the task inventory will entail the interviewing of nurses, structured observation of nurses performing their jobs, and investigation of additional materials, such as manuals.

The ''job descriptions'' that are part of online vacancies provide a rich source of information about both the tasks to be performed on the job and the necessary specifications, such as job knowledge. Existing methods of job analysis can be expensive and laborious in their data collection methods [41], and on top of that the reliability of data collected from job incumbents has been called into

[7] §2 ''Tasks'' paragraph (3).

[8] Section 2 ''Vocational Training'', §3 ''training target'', paragraph (1).

question [45]. So an alternative source such as online vacancies could both reduce costs and increase data reliability [55]. With the vast number of online vacancies available, the aid of text analysis techniques is needed. The task lists, resulting from the task inventory and the vacancy mining are subsequently administered to nurses in the form of a survey. In this survey nurses not only check whether the tasks presented are indeed part of their job, but also provide ratings of importance, frequency, and criticality. Finally the job descriptions resulting from the above are further validated by means of a panel of experts who decide on the final task lists that serves as the basis for the aforementioned comparison with the tasks that derive from the processes.

Beside the above described systematic nursing job analysis, a process modelling methodology is applied for formalizing tasks and related organizational knowledge [59]. The question is how to capture task-related organizational knowledge. One efficient way of identifying tasks and enriching the organizational knowledge-base in a systematic and controlled way, to support employees to easily acquire their job role specific knowledge, and to help govern human capital investment, is to extract, organize and preserve knowledge embedded in organizational processes. One of the overall objectives of business process management is the articulation of hidden knowledge in the context of production, services, and organizational activities [59]. In dynamic environments, both roles and required competencies are changing, therefore knowledge elicitation and articulation cannot go independently from the permanently updated business process model; hence the business process model is one of the most important ingredients of the knowledge to be captured [59]. In summary, our main approach for exploring job related knowledge is to extract it from information stored in organizational process models. This process structure will be used for building up the task related knowledge structure, i.e. the ontology model of processes.

Ontologies basically provide semantics and they can describe both semantics of the modeling language constructs as well as semantics of model instances [43]. There were already several projects investigating business process ontologies such as the SUPER project [31], but for the sake of the current project a new method for mapping process model elements with ontology concepts has been created.

In the first step process models are exported in the structure of ADONIS®[9] XML format. This format is machine readable, and well-formatted, as it is described in its schema file. All objects from the business process model will be an ‘‘instance’’ in the XML structure, the attributes have the tag ‘‘attribute’’, while the connected objects (such as the performer, or the input/output data, which are stored in another model in the ADONIS® tool) have the tag ‘‘interref.’’

Our model transformation approach aims at preserving the semantics of the business model. The general rule followed is to express each ADONIS® model element as a class in the ontology and its corresponding attributes as attributes of the class. This transformation is done with an XSLT script that performs the conversion. The script is adapted to the XML structure, and its usage is easy as we do not have to leave the XML-space with any kind of external application.

To specify the semantics of ADONIS® model elements through relations to the ontology concepts, the ADONIS® business model first must be represented within the *Job-Know* ontology. With regard to the representation of the business model in the ontology, one can differentiate between a representation of the ADONIS® model, language constructs, and a representation of ADONIS® model elements. ADONIS® model language constructs such as ‘‘activity’’, ‘‘as well as the control flow are created in the ontology as classes and properties’’.[9] Subsequently, the ADONIS® model elements can be represented through the instantiation of these classes and properties in the ontology. The linkage of the ontology and the ADONIS® model element instances is accomplished through the usage of properties [60]. ‘‘These properties specify the semantics of an ADONIS® model element through a relation to an ontology instance with formal semantics defined by the ontology’’.[9]

Since process models are not only used as a structural definition of tasks, but as the holder of the required knowledge to each task and their responsible roles, text-mining algorithms have to be run to gather knowledge elements from the process models [35]. Using a word association measuring, for instance, the association between the two words, i.e. taken from task and knowledge domain, e.g. *Task* (check-in)↔*Knowledge* (management), can be identified and computed. The larger the value calculated the higher the association between the detected task and associated knowledge [35]. The output of text-mining provides the base for merging the nursing domain ontology (see next section) with the Task ontology.

B. KNOWLEDGE DOMAIN

In general the non-ontological resources used in this phase are taken from the European Parliament and Council, DIRECTIVE 2005/36/EC[10] [16] and vocational training and examination regulation of occupations in nursing in Germany (known by its German abbreviation KrPflAPrV)[11] [3], [36]. This part is discussed by the authors in [32].

A further aim of our research is to create an ontology for the semantic representation of what is taught into nurses in VET. More precisely the ontology of nursing knowledge developed in the frame of the Med-Assess project [32], [34] is extended in the current study.

Representing content in an appropriate format, which is tailored down to the individual learner's context, is a great challenge for VET educators. As there are no identical

[9] ADONIS® Business Process Management Suite, BOC Information Technologies Consulting AG. http://www.boc-group.com/products/adonis/

[10] ANNEX V, Point 5.2.1

[11] according to §1(1)

learners with identical educational needs or professional progress, the problem of providing uniquely composed and personalized learning material is an evergreen issue [56]. In line with these challenges, one of the objectives of the Pro-Nursing project is to provide support to the whole learning cycle of nurses, independently of its form (e.g. tuition, training or education) and to provide access to complex, but personalized curricula or learning materials. The STUDIO system provides all those tools that can effectively enhance the individual learning experience. STUDIO has a dual focus: a) how to use ontologies for modeling learning content and b) how to explore missing knowledge areas of candidates and compose automatically such learning materials that directly addresses the shortcomings of the candidate.

The domain ontology model is the backbone of the STUDIO system that, on one hand, provides a formal description of the domain of interest, and on the other serves as a basis for the adaptive knowledge testing solution. Ontology-based approach provides support for capturing regularities in a single framework general enough to model the content management requirements of multiple institutions or applications. That is the reason why the ontological approach has been selected for modeling the learning content. In [64] a detailed description of the ontology structure (classes and relations) is presented.

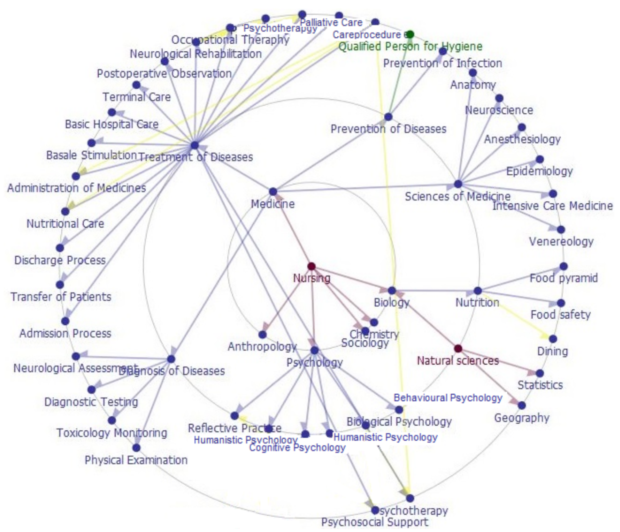

FIGURE 4. Visualization of Domain Ontology in the use-case of nursing.

Considering the aforementioned mechanism, the Job-Know ontology is built for the use-case of nursing where each node has got a number of test questions and related learning material. If a candidate takes the test, she starts at a more general level (of the ontology), and is led to the detailed level based on her answers. This is built like a ring structure as illustrated in Fig. 4. The inner circles are asking for the more general knowledge like nursing in general, while the more difficult or expert questions are on the outer rings. A candidate is only able to access these outer questions, after correctly answering the more general ones. If the candidate fails in her/his answers at the beginning, then the test will be ended and the results are evaluated and consequently presented to the candidate. The answers are categorized in three levels, namely accepted, not totally accepted and rejected. The *Test Engine* of Med-Assess calculates the test score in a numerical way: score of a more general knowledge element (ontology node) is determined as a percentage of correctly answered expert questions that are on the outer rings of this general knowledge element. In other words, first the percentage of correct answers is calculated on the outer most rings after which these percentages are summed up in the next (inner) level. Summing is continued until the most inner knowledge element is not reached.

V. CONCLUSION AND OUTLOOK

This paper introduces a semantic framework for developing a job knowledge ontology. It specifies the methodology for ontology development with a specific focus on two domains, namely "task" and "knowledge". The application of the framework was discussed in light of a use-case of nursing which is considered as a knowledge-intensive and experience-based occupation. In particular, health sector across Europe demand highly qualified nurses. The key to determine quality of nurses' job performance is determined as the ability and skills for successfully applying domain specific knowledge in various situations. Nursing education is strongly linked to on-the-job training and learning by doing. To fill existing knowledge gaps, nurses need to participate in (continuous) vocational education and training (e.g. workshops or online courses). Nursing tasks can be modeled in reference to the care processes, thus identifying all performed nursing actions. The nursing tasks should be analyzed and later mapped against appropriate knowledge and skills. The framework for creating nursing task and knowledge ontologies has been discussed in detail.

Using the task and knowledge ontologies resolves the identification of an individual's shortcomings in the knowledge domain in relation to the required tasks for a specific type of occupation, such as nursing. Employing the framework, therefore, facilitates semantic modeling of an occupation based on knowledge and job requirements, i.e. knowledge and task performance linkage, and strengthens the quality of job analysis for tailoring the needs of the labor market to educational curricula.

In particular, the added value of the job knowledge ontology with regard to the labor market needs is specifiable, first in a line with career guidance for job applicants, -seekers and -holders such as nursing students, novice and senior nurses [34]. Second, the ontology is used for assessing the qualification level of job applicants and job holders by recruiters and job owners [34]. The developed ontology, therefore, has been deployed in the context of the Med-Assess system for the assessment of job knowledge of test takers and providing recommendations for further education and training [32], [44]. Furthermore, the job knowledge ontology is currently under further enrichment in the context of the Pro-Nursing system, towards providing learning recommendations based on eight nursing curricula used across Germany [59]. In fact the pilot trial of the Pro-Nursing project will provide evidences for extracting the job knowledge gaps of German nurses and can be used by labor policy makers and for further development of nursing curricula.

Job knowledge analysis, as a progressive research, requires a simultaneous effort on both the supply and demand chain i.e. addressing dynamic changes (e.g. due to technology, process or policy changes) in the labor market, which should be responded to either by exploiting existing knowledge or exploring new knowledge.

In addition, nurses develop their career profile by practicing the lessons in various situations over time. Therefore former experiences of nurses are a valuable source for enriching the developed Knowledge-Base. The experiences should be extracted e.g. using structured interviews, classified and validated by experts. Text-mining algorithms can aid in automating data processing, particularly for extracting knowledge and task objects from the poor or unstructured data sources, e.g. nursing reports or available web data sources, such as nursing forums, job vacancy announcements, and experience sharing portals.

Hence, future research should address the dynamics of our job knowledge ontology with regard to changes in the occupations and educational systems, particularly by employing text-analytics and incorporating experiences of knowledge holders.

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