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Core-O: A Competence Reference Ontology for Professional and Learning Ecosystems

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Abstract. There are a number of standards aiming to facilitate the exchange of competence data in the educational and job market areas. Despite their relevance, we have observed that they could benefit from an in-depth analysis of the notion of *competence*, given its central role in the intended application areas. This includes addressing facets of competence not only when attributed to particular individuals, but also when required by occupations in general. A comprehensive account for competences should ideally account for competence-related elements such as knowledge, attitudes, skills. It should also countenance their performance—related to tasks, their context, and outcomes—as well as their evolution over time (in order to account for the notion of 'proficiency'). While some of these aspects are addressed in the existing standards, they are addressed in a partial manner, and a comprehensive conceptualization that can serve as a reference for articulating the various perspectives is still lacking. This is the focus of Core-O as a well-founded competence reference ontology.

Keywords. Reference Ontology, Competences, Core-O

1. Introduction

Learning and professional ecosystems, which include companies, educational institutions, and governments, have become increasingly dynamic, large, and complex as technology has advanced in society and especially in the job market. The ongoing pursuit of human development prompted actors in these ecosystems to develop Human Resource Management (HRM) and Vocational Education and Training (VET) policies. One of these advancements has been the steady shift away from content-based methods and toward competence-based methods, which reflects a shift from a Supply-Oriented Model to a Demand-Oriented Model [1,2]. This includes the implementation of competency-based curricula, courses, training methods, assessments, and professional and job selection.

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There are many reasons for the increasing adoption of competence-based approaches, such as the establishment of lifelong learning policies in some countries and the prioritization of non-formal and informal learning in companies, universities, and schools [2]. In these contexts, the focus on competences (rather than simply content delivery) promotes more profound integration between formal education, vocational training, and professional development in these ecosystems. In addition, competence-based approaches are considered key to improving workforce skills and professional qualification and promoting better work mobility [1, 2].

As part of these policies, many frameworks and standards that have been adopted by governments and institutions. Several of these have been used to support the exchange of skill and competence data in the educational and job market areas. In this context, well-known initiatives include the Occupation Information Network (O*Net)[2], the European Skills, Competences, Qualifications and Occupations (ESCO)[3] classification, the Human Resource XML (HR-XML)[4] specification; the IEEE Reusable Competency Definition (IEEE RCD) [3]; and the IMS Reusable Definition of Competency or Educational Objective (IMS RDCEO)[5]. Other significant initiatives related to these policies are the Europass standards [4], the EURES Portal[6], among others. The resulting standards are used to facilitate the sharing of competence-related data from professionals (concerning digital credentials, open badges, awards, curriculum vitae, certificates, and diplomas) and from the job market (concerning job vacancies and learning opportunities), enhancing employee mobility, job finding, etc.

Despite the contributions of these various initiatives, we have observed that they could benefit from an in-depth analysis of the notion of *competence*, given its central role in the intended application areas. This includes addressing facets of competence not only when attributed to *particular individuals*, but also when *required of occupations in general*. A comprehensive account for competences should address competence-related elements such as *knowledge*, *attitudes*, and *skills*. It should establish the semantics of these various elements and reveal how they contribute to the formation of competences. It should also address the *performance* of competences—related to tasks, their context and outcomes—as well as their evolution over time (proficiency). When some of these aspects are addressed in the existing standards, they are addressed in a partial manner (e.g., focusing only on the individual perspective or only on the general occupation perspective), and a comprehensive conceptualization that can be used as a reference for articulating the various perspectives is still lacking. This is the focus of Core-O as a well-founded competence reference ontology.

The development of Core-O was based on the Systematic Approach for Building Ontologies (SABiO) [5], focusing on: (i) vocational education and training (VET) institutions (e.g., universities, vocational schools, etc); (ii) organizations; (iii) human resource (HR) sectors, and (iv) government entities; that need to: (i) inter-operate and exchange data related to human capabilities; and (ii) improve their competence-based approaches by using the proposed ontological artifact with Semantic Web techniques. In order to propose the ontology, we studied the competence literature, some competence frame-

[2]https://www.onetonline.org/
[3]https://esco.ec.europa.eu/
[4]https://www.hropenstandards.org/
[5]https://www.imsglobal.org/
[6]https://europa.eu/eures/portal/

works, other competence ontologies, and finally competence standards, such as ESCO, O*Net, EURES, and Europass. We also investigated the relevant conceptual distinctions and analyzed them under the light of the Unified Foundational Ontology (UFO) [6]. The reference ontology was modeled with OntoUML [6] and an operational OWL version was obtained by automated transformation from the reference ontology.

This version of Core-O was built up from our previous works reported in [7–9], where we focused on incorporating competence-related elements in Enterprise Architecture (EA) models by ontological analysis. Here, we further improved the conceptualization by incorporating the *competence type* sub-ontology (to account for competences when required of occupations in general) and by addressing *competence performance* aspects (e.g., resource, input, output, outcome, proficiency, and evidence). We also improved the representation by employing OntoUML for the reference ontology and implemented an operational OWL version; both are now published following FAIR practices.

This paper is structured as follows: Section 2 explores the fundamentals of competence, skills, knowledge, and attitudes (following [9]). Section 3 describes the development of Core-O, emphasizing the role of Unified Foundational Ontology (UFO), OntoUML and gUFO in the construction and generation of the ontology artifacts. Section 4 presents the Core-O ontology via its sub-ontologies and their applications. Section 5 evaluates Core-O's enhancements over the European standards ESCO and Europass. Section 6 compares Core-O with other ontologies and competence frameworks, highlighting its integrative capabilities. We conclude this work in Section 7 with a summary of Core-O's contributions, potential applications, and future research directions.

2. Competence and Related Concepts

In a general sense, "competence"[7] is understood as a kind of human ability [1, 10, 11]. It consists of both an implicit and an observable component [12, 13]. From the implicit perspective, competence is formed by a latent cognitive structure that cannot be directly measured [12]. According to [10], competence is a result of the association of internal structures of declarative and procedural (task-related) knowledge that inhere in an individual. From the observable perspective, competence is formed by the combination of perceptible characteristics, such as the "well-known" *knowledge*, *skills*, and *attitudes* (KSA) elements. These elements enable an individual to perform *tasks* efficiently [11, 13]. In this sense, competence generally has a performance-oriented aspect, more focused on "results" and task accomplishments [1, 11]. Wood and Power [10] reinforce this facet, defining competence as the ability to use knowledge or skills to act effectively to achieve some purpose through successful performance.

The aforementioned frameworks and standards adopt a set of competence-related concepts in their models. Competences are formed by the combination of *knowledge*, *skills*, *attitudes*, and other *characteristics* elements (e.g., personal traits, humor, temperament, among other qualities) [11, 13]. *Skills*, not unlike competences, allude to the capability to perform actions. The notion of skill has been defined in multiple ways, each of which emphasize a particular aspect of it. For example, Rodriguez [14] defines a skill as the ability of an individual to perform a task (discrete unit of work) well. Esposto [15]

[7]We adopt in this work the term "competence" to refer to an individual's performative ability, and refrain from using the term "competency".

defines it as a set of general procedures that underlies the application of knowledge in a domain. [16] defines skills as processes that act on knowledge in an application domain.

Knowledge is typically associated with internal representations of facts, principles, or theories in a specific domain [12]. It is the cognitive outcome of the assimilation of concepts, ideas, or figures related to a specific topic [17]. Knowledge is linked to a specific person, the bearer, making it is difficult to transfer and assimilate [18]. Knowledge is assimilated when it becomes a part of the bearer's internal structure. As new information or facts are added, the structure changes [10]. *Attitudes* are generally associated with an individual's behavior [11, 16]. Others associate them with personality traits or the professional's psychological and emotional nature [17]. Attitude is a tendency to act (or feel) in a given situation [19]. It is based on assumptions, values, and beliefs, so they are non-neutral with respect to actions [19]. In general, definitions of attitude take into account the following characteristics: (i) mental state; (ii) values (beliefs, emotions); and (iii) predisposition to act or behave [20].

Although competence is commonly defined as a set of attitudes, skills, and knowledge, authors consider further types of elements to be components of competences. Personal traits, behavior, mindset, patterns of thinking, and tacit and explicit knowledge are considered by some authors to be part of competence [13]. This is recognized also by Westera [12], for whom competences have additional elements that are not clearly defined. According to Miranda et al. [11], competences are also formed by a set of personal characteristics required to perform tasks in a specific context, leading the authors to consider the KSAO model, a variation of the KSA model that includes "Other Characteristics" as a fourth element to define competence.

The concept of *performance* is prevalent in competence *definitions*. In an organizational context, performance is frequently related to "competence manifestation", such as completing a task, achieving a desired goal [1, 11], or generating a result. In this sense, based on [12], competence is seen as an implicit potentiality, and *performance* is seen as an external manifestation of it, i.e., the way that potentiality manifests itself under the influence of external (environmental) and internal (human) elements. Likewise, according to [10], performance is defined by the ability to access and apply internal knowledge (and skill) structures. Based on this definition, performance can be seen as the practical "application" of competence in a given situation. Concerning competence manifestation, some competence models and definitions take into account the context, resources, and tools required for competence manifestation.

The concept of *proficiency* is also common in competence *definitions*. Proficiency represents the experience (i.e. expertise) that a person has in a competence (or skill) [10]. Generally, in a practical sense, it is referred to as a qualitative level or degree (i.e. low, medium, high) associated with a competence (or skill) [11] whose value varies over time. The various competence frameworks often consider distinct levels of proficiency for competences and skills [1] related to a position or area. Examples of such levels include 'awareness', 'supervised practitioner', 'practitioner', 'lead practitioner', and 'expert'. Commonly, for each identified level of proficiency, there is some expected evidence, some indicator, observable characteristics (e.g. the KSA elements), observable results (e.g. products, outcomes), and behaviors (e.g. activities, tasks performed).

3. Foundational Baseline

We build up the competence ontology on the UFO foundational ontology [21]. UFO includes domain-independent categories, starting with the distinction between *types* and *individuals*. *Individuals* are further classified into *perdurants*, *endurants*, and *situations*. *Perdurants* (also termed events) are *individuals* that occur in time (i.e. activities, actions, tasks, processes). *Endurants* are individuals that persist in time while retaining their identity (i.e. people, organizations, projects, cars). *Endurants* include *moments* and *substantials*. *Moments* are reified aspects of an *endurant* (termed its bearer), on which they are existentially dependent. All *endurants* (including moments) can have essential and accidental properties and can change qualitatively while retaining their identity. This is an important feature of UFO for Core-O since we are concerned with individual competences and their evolution in time. *Moments* include *intrinsic moments*, which are existentially dependent on a single *individual* and can be either a *quality* (for which we can establish a space of values, e.g. color, height, weight, and electrical charge) or a *mode* (not reduced to a value). Following [22], we assume that *modes* include what are known as *dispositions* ("powers" or "capacities") in the philosophical literature [23] (such as a magnet's disposition to attract ferrous materials or Anna's English speaking skill). *Dispositions* are modes that can be manifested through the occurrence of *perdurants* (possibly agents' intentional actions, such as Anna's speaking English). In *situations* where *dispositions may manifest*, they are said to be "activated" (e.g., when a magnet is close to some ferrous material, when Anna is prompted to introduce the topic of a meeting). Given our focus, we also distinguish *Agents* as objects that perceive *events* and perform *actions* based on their *intentions* [24].

An important difference between UFO and other top-level ontologies such as BFO [25] and DOLCE [26] concern its taxonomy of types. This is key to Core-O given that the domain requires us to explicitly model types (of competences, skills, tasks) at the generic (individual-independent) level. UFO has a rich taxonomy of endurant types classifying them according to the metaproperties of sortality, ridigity and external dependence (originating from OntoClean [27]). *Types* are classified into *sortals* (kinds, subkinds, phases and roles) and *non-sortals* (categories and mixins) depending on whether they supply identity criteria to their instances. *Rigid sortals* are those that apply necessarily to their instances, including *kinds* ('person', 'car', 'organization') and their *subkinds* ('Brazilian born', 'sedan', 'hospital'). Anti-rigid sortals include *phases* whose contingent classification conditions are intrinsic (e.g., 'adult' and 'child') and *roles* whose contingent classification conditions are relational (e.g., 'student', 'employee'). *Nonsortals* represent common properties of individuals of multiple *kinds*: (i) *categories* subsume multiple rigid types (e.g. 'mammal' subsuming 'human' and 'cat'); (ii) *phase mixins* subsume multiple *phases* of distinct *kinds* (e.g. 'adult mammal'); and (iii) *role mixins* subsume *roles* of distinct *kinds* (e.g., 'customer' subsuming 'personal customer' and 'organizational customer').

The foundational distinctions introduced by UFO can be incorporated into domain ontologies using a well-founded UML profile dubbed OntoUML [21, 28]. Dedicated tool support (`https://github.com/OntoUML/ontouml-vp-plugin`) is available to ensure the ontologies produced with OntoUML follow the foundational rules established in UFO [28,29]. OWL 2 DL implementations can be obtained automatically and leverage the UFO implementation in OWL dubbed gUFO [30] ("gentle" UFO). gUFO implements some important patterns to cope with recurrent representation problems in OWL ontologies, including relationship reification and, importantly to our purposes here, variation over time (based on situations) (see [30] for details).

4. The Competence Reference Ontology (Core-O)

The competency questions and requirements for our ontology are available in the Core-O repository (`https://purl.org/coreo/repo`). The proposed ontology is formed by two main sub-ontologies: (i) the *personal competence ontology* and (ii) the *competence type ontology*. The personal competence ontology focuses on individuals [7, 8]. This aspect is important to represent the individual capabilities in curricula for the job market, learning opportunities, and job vacancies, as happens in the Europass initiative, for example. Because the personal competence ontology focuses on the individual, it can be used to help organizations implement competence-based approaches such as competence identification, assessment, comparison, training, professional selection, and so on. However, as discussed in Section 2, competence frameworks and standards generally focus on generic (or universal) modeling of competences that are not specific to an individual: this perspective is accounted for in the competence type ontology.

Figure 1 shows the personal competence ontology. As illustrated, *humans* are *agents*; they may perform *human tasks* and bear *human aspects*. *Human aspects* are all *intrinsic moments* that inhere in a person. *Human aspects* may be the subject of certain *evidence*, which are objects such as certificates (of a course or project participation), degrees, diplomas, credentials, testimonials, products developed, awards, badges, etc. *Human aspects* encompass, among others, what we call *human capabilities*, which are *dispositions* of special kinds that inhere in a *person* and subsume both *personal competences* and *skills*. *Human capabilities* have *proficiency*, a quality representing the intensity, "level" or "degree" of that *capability*.

Because of their dispositional nature, when *capabilities* are activated in a certain *human capability manifestation context* they are manifested through *human tasks*. They are *events*, more specifically *actions*, which involve the manifestation of one *human capabilities* and are related to a unit of work or result. These results include *artifacts* created/changed by the task, called here *task outputs*. Besides this more objective result, the competence manifestation can also generate a new *situation*, called here *task out-*

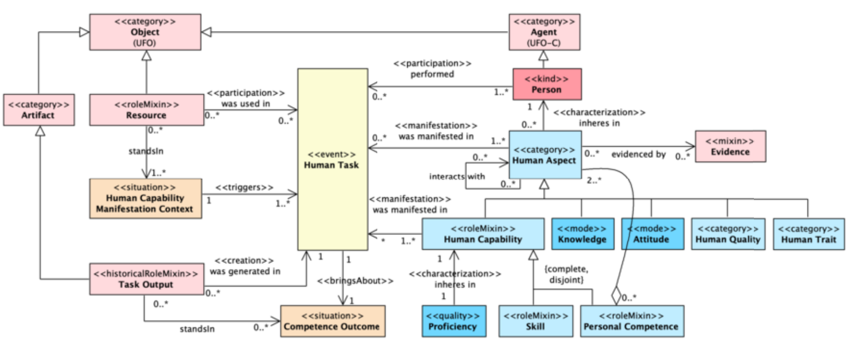

Figure 1. Proposed Personal Competence Sub-Ontology

come (e.g., the satisfaction of the customer). In this sense, *resources* are *objects* used to create/change some *artifact*. We consider the *manifestation context* to be a physical and/or social context that enables competence manifestation, e.g., a workspace formed by *resources* (tools, technologies, or human resources) needed in the human capability manifestation.

Personal competences (unlike *skills*) are composed of other *human aspects*, such as *skills*, *knowledge*, *attitudes*, or other *human characteristics*, which include *human traits* (e.g., Mary's humor and temperament) and *human qualities* (e.g., John's age, height, and gender). *Personal competences* can be even composed of other ones. As competence is a compound entity, when it is manifested in a task, its "elements" are manifested too.

The Competence Type Sub-Ontology The personal competence ontology presented in the previous section addresses the individual level. That level is necessary in order to account for specific persons, their particular capabilities, as well as the tasks they have performed by manifesting them. This sub-ontology addresses the type level; here, we are interested in *types of capabilities* (including their *phases*) that are required in certain *roles*, the *types of tasks* they manifest, the *types of artifacts* relevant to them, etc.

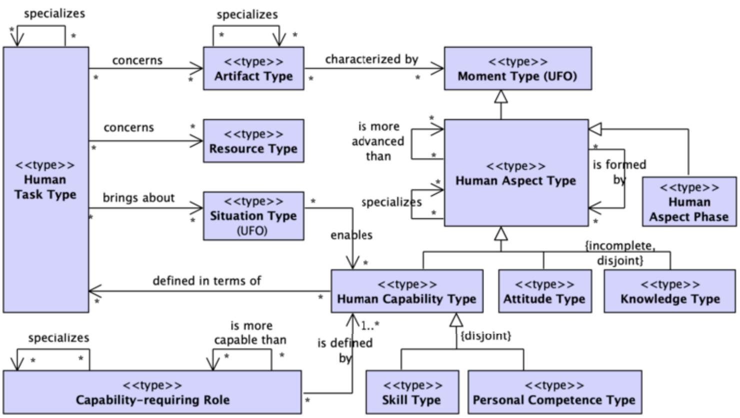

Figure 2. Proposed Competence Type Sub-Ontology

As depicted in Figure 2, *human aspect type*, as the name suggests, regards "generic" types that classify the *human aspects*, not those related specifically to a specific individual, i.e. *types* of *knowledge*, *attitude*, *skill*, and *competence*; *human capability type* is a subtype of *human aspect type* that can be described or "defined by" *human task types*; *human task type* classifies tasks performed by a *person* as a manifestation of some *human capability*, can be detailed by (generic) *situations types* that represent types of outcomes generated by *human task types* instances (e.g. customer satisfaction after receiving a deliverable), and are concerned with *resource types* and *artifact types*; and, finally, *artifact types* classify the results of a *human capability* manifestation and can also be characterized by certain *moment types* (e.g., the usability of web pages).

In addition to types corresponding to elements in the personal competence ontology, the competence type sub-ontology addresses two new distinctions: (i) *capability-requiring role* and (ii) *human aspect phase*. A *capability-requiring role* allows the "generic" representation of formal or non-formal human positions, occupations, or functions that can be performed contingently by an "individual" *person* with *capabilities* of certain *capability types* (e.g., software engineer, or project manager). In its turn, *human aspect phases* enable the "generic" representation and specification of "*phases*" or stages (e.g. basic, intermediate, advanced) in accordance to the level of "intensity" or "profoundness" of a *human aspect type* (e.g., the "advanced" phase of "Java programming skill"). In this sense, these "*phases*" of a *human aspect* correspond to the qualitative development of its characteristics.

One distinction of this sub-ontology is the specialization between the types. For example, a *capability-requiring role* can "specialize" a more generic role (e.g., the "front-end developer" role specializes "software developer"). In the same way, a *human aspect type* can specialize other (more generic) *human aspect types* (e.g., "Java programming skill" specializes "programming skill"); an *artifact type* can specialize (more generic) *artifact types* (e.g., "Java code" specializes "code"); and, a *human task type* can specialize other (more generic) *human task types* (e.g., "Java programming" specialize "programming"). Based on their phase (proficiency), human aspect type can *be more advanced than* others, as shown in Figure 2. E.g., *senior software development* competence is more advanced than *junior software development* competence. As a result, a capability-requiring role can *be more capable than* others (e.g. the "senior software developer" role is more capable than "junior software developer" one). This distinction is depicted in Figure 2. Concerning their structure, a *human aspect type* can also be formed by others, on many levels, as a hierarchical structure (e.g., "full-stack development competence" is formed by "front-end dev. competence" and "back-end dev. competence"). If a human aspect type t_1 is formed by another human aspect type t_2, instances of t_1 are composed of instances of t_2.

Figure 3 depicts how the two sub-ontologies are connected. As the figure details, *human aspects* instantiate distinct *human aspect phases* (of a correspondent *human aspect type*), in distinct moments. E.g., the "software development competence" of John, which instantiates the "software development competence type", can instantiate distinct *human aspect phase*: the "*basic* software development competence" in a moment and the "*advanced* software development competence (aspect phase)" in other. In a similar way, a *person* can instantiate a *capability-requiring role* (a specialization of *person type*) in one moment and not in another. In this case, this instantiation just would happen if the *person* have the *human aspects* that instantiates the *human aspect types* which describe the correspondent *capability-requiring role*. For example, John just would be a "senior software developer" if he has, at least, the "senior software development competence".

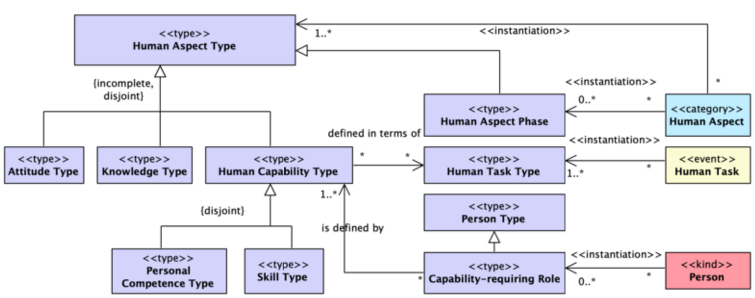

Figure 3. Instantiating the Competence Type Sub-Ontology

Implementation and Release After creating the OntoUML model for the competence ontology, we published it in the OntoUML/UFO FAIR catalog (https://scs-ontouml.eemcs.utwente.nl/), which is a structured, open-source catalog of OntoUML and UFO-based ontology models [31]. Following, we generated the ontology in OWL by using gUFO and made the ontology (both the diagram and the OWL) release using a permanent URI (http://purl.org/coreo), with a repository available in Github (http://purl.org/coreo/repos). As part of the ontology evaluation procedures, we have ran the FOOPS! Ontology Pitfall Scanner for the FAIR principles [32], with a minimum requirement of 93% FAIRness overall score. In according with SABiO's development process, we tested the ontology with scenarios that corresponded to specific competency questions. The ontology was instantiated, validated, and verified in each of these scenarios. This verification took into account the temporal aspect of personal competence. In terms of validation, the main strategy was creating scenarios representing the competence-based approaches (mainly, gap analysis) in organizational context in compliance with competence frameworks.

5. Implications of the Reference Ontology to Existing Standards

We demonstrate the applicability of Core-O in this section by examining the ESCO and Europass competence/skill vocabularies in light of the reference ontology. We show that the representations based on Core-O can improve the representation of competences and related elements in scenarios that are typical for the application of these standards.

ESCO's Scenario ESCO is one of the most relevant ontologies and datasets about competences and skills. It is employed by other important initiatives in this context such as Europass and EURES. ESCO basically addresses concepts related to *occupation*, *skill*, and *qualification*. For example, ESCO defines for the *software developer* occupation a couple of skills, such as "developing software prototypes", "debugging software", "defining technical requirements", "developing creative ideas", "adapting to changes", among others; and also knowledge such as "engineering principles", "computer programming", Java, among other technologies. ESCO does not consider *tasks*, *resources*, and *artifacts*. Besides this, the distinction between *skill* and *knowledge* differs when compared to Core-O, to the prevailing literature [16, 33–35], and to other competence framework descriptions. ESCO also does not allow the representation of occupations in distinct abstraction levels, not allowing the description of generic roles' capabilities (e.g. the common skills of an engineer independently of its type).

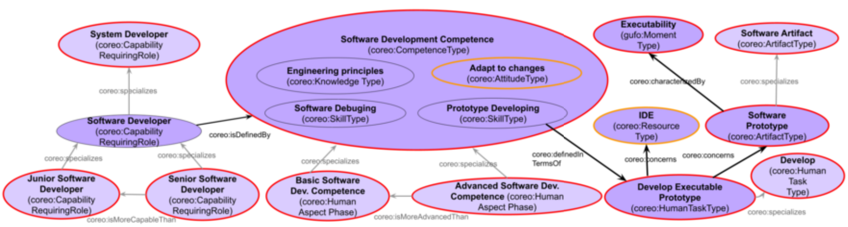

Figure 4. Ontology Instantiation in OWL - ESCO Scenario (additional concepts with *red* border, adapted with *orange*)

Figure 4 illustrates how the proposed ontology can improve the representation of these skills and competences for the presented example described in ESCO, related to the *software developer* occupation. The figure illustrates an instantiation of Core-O showing this scenario. As is depicted, the *software developer* occupation is modeled as a *capability-requiring role* that is a specialization of *system developer* role, a more generic one. The *Software developer* occupation can also be specialized into junior and senior software developers (evolution stages). In this case, the former is less capable than the latter, as depicted. Another distinction is that in ESCO the occupation is described through a couple of skills that are not aggregated or even related. Otherwise, with Core-O, it is possible to aggregate these skills in a more meaningful way, through correspondent competence types, besides relating them through "more advanced than" relationship. For example, the presented ESCO's skills, associated with the software developer occupation, can be aggregated as "software development competence", as depicted. In this case, this competence type is formed by "prototype developing", "software debugging", among other skills; and also ESCO's knowledge such as "engineering principles" knowledge (nested representation). An important distinction in applying Core-O to ESCO is related to the changes in semantic classification this ontology brings. For example, the "adaptation to changes" (in orange) is represented in ESCO as a skill while is represented as *attitude* in the proposed model. Other knowledge representations can also be classified more accurately based on Core-O. For example, in ESCO, "computing programming" is considered knowledge but according to this ontology is a skill type. The same occurs with the ability to program in specific programming languages, such as Java, Python, etc. ESCO classifies these abilities as knowledge besides they are considered kind of coding skills based on this ontology. These examples indicate that ESCO lacks well-established semantics regarding human capability, not properly distinguishing competence elements, which can have implications in semantic web approaches (e.g., reasoning).

The detailing of human capabilities through task, resource, and artifact distinctions is one of the most significant improvements in semantic distinctions based on Core-O. ESCO, which includes these aspects implicitly in the skill descriptions, does not take into account any of these concepts. For example, ESCO's definition of the "developing software prototype" skill mentions the "development" task and the "prototype" artifact textually but not explicitly. In its "skills" descriptions, ESCO also considers indirect resources, such as knowledge of the "integrated development environment" (IDE). Otherwise, by using this ontology it is possible to improve this representation. As depicted in the figure, the "prototype developing" skill is defined by an "executable prototype development" task. This task is a specialization of "development task", a more generic one. As shown, the "executable prototype development task" concerns the IDE resource and "software prototype" artifact. This ontology also allows the categorization and characterization of artifact types, as in the case of the "software prototype" which is a specialization of a "software artifact" type and is characterized as an "executable artifact".

Europass's Scenario In terms of individual competences, the Europass is the most relevant in the context. Europass is an EU initiative to increase the transparency of European citizens' qualifications. Many documents, such as the Curriculum Vitae (CV) and the European Skill Passport, can be created through its portal. Individuals can register their experiences, qualifications, and, most importantly, their competencies and skills in this context. Behind this portal is a meta-model containing many competence-related concepts addressed by the proposed ontology.

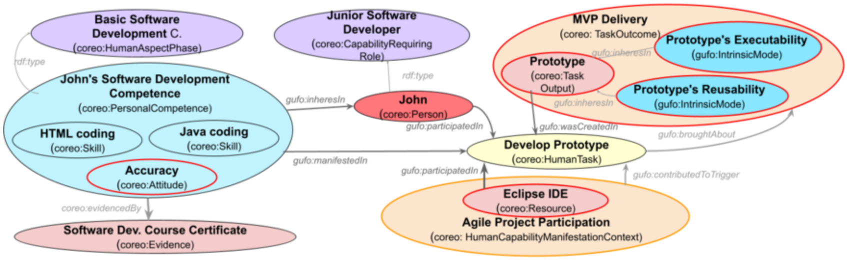

Figure 5. Ontology Instantiation in OWL - Europass (additional concepts with *red* border, adapted with *orange*)

In the Europass CV, it is possible to associate personal competences and skills with a professional, named "candidate", regarding the related "proficiency level". Besides this, to prove competence/skill, the candidate can inform "qualifications", "projects", "employment references", "activities", and "publications" (i.e., productions, products, results). The learning model addressed by Europass also considers that an "agent" (person) can search for "learning opportunities" related to desired "learning outcomes" and then register "learning activities", "learning achievements", "learning outcomes", and also "qualifications", "awards", and "digital credentials".

All these mentioned concepts, addressed by the Europass, are encompassed by the proposed ontology. In this case: (i) Europass's candidate/agent concepts are types of *person*; (ii) Europass's skill concept is equal to *skill*; (iii) Europass's personal competency is equal to *personal competence*; (iv) Europass's proficiency level is associated with *proficiency*; (v) Europass activity and learning activity are types of *task* from an ontology; (vi) Europass publication (e.g., book, map, engraving, photograph, piece of music, or other work) and learning achievement are types of *task output* (*artifact*); (vii) Europass's certificate, qualification, project, experience, achievement, award, digital credential, and employment reference are kinds of *evidence*; and (viii) Europass's learning outcome is equivalent to *task outcome*.

As in the case of ESCO, this ontology also encompasses some semantic improvements to the Europass ontology, especially regarding the representation of competence performance of an individual (i.e., tasks, outputs, inputs, resources, etc). This is highlighted in Figure 5, which instantiates the ontology model to a specific individual. As depicted, John (*person*) has the "software development competence" (*personal competence*) at the basic level (human aspect phase). His competence is formed by "HTML coding" and "Java coding" skills but also by his "accuracy attitude" (nested representation). This is proved by the "software development course certificate" (*evidence*). His competence is manifested by the "developing prototype" *task*, triggered by the "agile project participation" (*manifestation context*), as shown. In this *task*, he uses the "Eclipse IDE" as a *resource* (part of the context). Then, John generates as a result a "reusable" and "executable" prototype (*task output*), which is part of a MVP delivery (*task outcome*). As highlighted in the model, this ontology instantiation has some semantic improvements concerning the Europass model. As shown, with this ontology it is possible to distinguish the *manifestation context* and needed *inputs* and *resources*. It is also possible to represent explicitly the results of a competence manifestation. In this case, this ontology allows the representation of the *outcomes* and related *outputs*. Besides this, it is possible to represent the *qualities* associated with the used/created/changed *artifacts*. Finally, it is possible in this ontology to represent *knowledge* and *attitudes* related to *personal competence*.

6. Competence Standards Harmonization and Related Works

It is critical for the effectiveness of these lifelong learning and VET policies that those competence models share well-established semantics regarding competence-related concepts. Some of the discussed models already are integrated. Europass, for example, employs EURES, which employs ESCO. However, a well-founded competence ontology that encompasses all of these models can extrapolate their potential application in new situations. In this context, the proposed ontology can aid in the better integration of the previously discussed competence models, as well as some potential applications. As a result of our analysis, we will present a semantic correspondence between the proposed concepts of this ontology and those addressed by the following competence standards: Europass, EURES, ESCO, and O*Net. As shown, Table 1 presents this comparison.

As it is shown, (i) *capability-requiring role* (ontology) generalizes *occupation* (ESCO and O*Net), and *open position* (EURES); (ii) *human aspect phase* (ontology) generalizes *level* (O*Net), *proficiency level* (Europass), and (*required/desired) proficiency level* (EURES); (iii) *competence type* is similar to (complex) *skills* related to *occupation* (ESCO), the bundle of *skill*, *knowledge*, and *ability* related to *occupation* (O*Net), and *position competence type* (EURES); (iv) *skill type* (ontology) is equivalent to (basic) *skills* (ESCO), *skill* (O*Net), and *skill type* (Europass); (v) *knowledge type* is similar to *skill* assigned as *knowledge* (ESCO) and *knowledge* (O*Net); (vi) *attitude type* is equivalent to *abilities* (O*Net) and *transversal skills* (ESCO); (vii) *human task type* is equivalente to *task* and *work activity* (O*Net) and *activity type* (Europass); (viii) *artifact type* is equivalent to *publication type* (Europass); (ix) *situation type* (ontology) is equivalent to *work context* (O*Net) and *position location* (EURES); and (x) *resource type* (ontology) generalizes *tools* and *technology* (O*Net).

Table 1. Competence Standards Alignment

Concept	ESCO	O*Net	EUROPASS	EURES
Capability-req. Role	Occupation	Occupation	-	Open Position
Human Aspect Type	-	-	-	-
Human Aspect Phase	-	Scale (Level)	Proficiency Level Type	Required/Desired Proficiency Level
Human Cap. Type	-	-	-	-
Competence Type	(Complex) Skill	-	-	Position Comp. Type
Skill Type	Skill	Skill	Skill Type	-
Knowledge Type	Skill (Knowledge)	Knowledge	-	-
Attitude Type	Transversal Skills	Abilities	-	-
Human Task Type	-	Task/Work Activity	Activity Type	-
Artifact Type	-	-	Publication Type Creative Work Type	-
Situation Type (UFO)	-	Work Context	-	Position Location
Outcome Type	-	-	-	-
Resource Type	-	Tools and Technology	-	-

Related Works. There have been a number of works recently on ontology-based competence representation. They can be considered a natural evolution of competence data standards for interchange between systems, such as HR-XML, leveraging ontologies to improve the semantics of competence data. Most of the related works analyzed focus on the individual level, on individual competence, as in [7, 8]. For example, Miranda et al. [11] propose an ontology that takes into account personal competence distinctions including proficiency. As a form of evidence representation, the work also represents some competence manifestations (as generated documents). Paquette [16] also considers personal competence distinctions with performance indicators in the ontology, but in greater detail than [11]. The author takes into account various types of performance, such as frequency, scope size, autonomy, and complexity level. Tarasov [33] also proposes an ontology that takes proficiency level into account. Aside from that, the author considers the Task and Artifact (Resource) concepts, similarly to our work. Beverly et al. [36] identifies the notions of 'skill', 'ability' and 'occupational disposition' as subtypes of dispositions in BFO [25]. Although that work refers to *types* often in the text to account for 'occupations' (using expressions such as "occupations understood as a type of disposition"), the ontology itself does not address the type level.

Other works, that focus on the type level (or both), allow the representation of *competence types* (and *skill types*) as related to some *human functional role*. Among these, a few consider a notion corresponding to *capability-requiring role*, such as *role* [11,33,34] or *job situation* [37]. Regarding *human capability types*, most related works consider this distinction related basically to *competence type* or *skill type*. On the other hand, only a small number of works consider other *human aspect types* [11, 35, 37], mainly concerning *knowledge type* and *attitude type*. Likewise, only a few consider the *human capability phase* distinction in some form [33, 38, 39]. In this sense, most of the works define concepts such as *proficiency level*, *level of competence*, or *level of skill* [11, 13, 16, 40]. The *human task type* concept is vaguely considered only in some of the works [35, 39]. No concepts related to the *human capability type* results (as *artifact type* or outcomes) were considered in related work. In addition, none of these related works generalize a notion akin to *human aspect phase*, which can be applied to knowledge and attitude in addition to skills and competences. Besides this, none of the related works considers the relations between types that were addressed in Core-O.

7. Final Remarks

This paper reported on Core-O, a competence reference ontology based on the Unified Foundational Ontology (UFO). The ontology was developed using SABiO's ontology engineering approach. We have shown it capable to elaborate application scenarios beyond the representation capabilities of ESCO's and Europass' competence standards. A comparison to other standards was offered, including O*Net and EURES, showing Core-O can be used as a reference to align competence standards. The main improvements of Core-O over competence standards, frameworks, and related works concern well-founded distinctions on: (i) *competence elements* including knowledge, skill, and attitude; (ii) *manifestation context* including resources and inputs; (iii) *competence performance* including task, outputs, and outcomes; and (iv) *competence-related types* including relationships between these types.

The main outcomes of this research are: (i) an *ontological artifact* proposed in the OntoUML language; and (ii) an *ontological artifact* written in OWL using gUFO [30]. Both were made available in accordance with the FAIR principles. In terms of potential applications, the proposed ontology can specifically assist in (i) *annotating semantically* competence-related artifacts such as curriculum, job postings, learning objects, resources, professional profiles, task logs, logbooks, and learning diaries; (ii) *integrating semantically professional data* from internal systems (organizations, VET institutions) and external ones (e.g., professional networks such as LinkedIn); (iii) *facilitating semantic search* and matching of professionals and occupations; (iv) assisting with semi-automatic skill/competence matching in gap analysis, and (v) aiding with competence/skill identification/assessment using ontology-driven data. Future work could delve deeper by addressing concepts such as *learning outcomes* and *objectives*. Finally, the proposed competence representation patterns should be validated in case studies concerning the applications mentioned above.

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References

[1] Sampson D, Fytros D. Competence Models in Technology-Enhanced Competence-Based Learning. In: Handbook on IT for Education and Training. Springer; 2008. p. 155-77.

[2] Deist FDL, Winterton J. What Is Competence? HR Development International. 2005;8(1):27-46.

[3] IEEE. IEEE Standard for Learning Technology-Data Model for Reusable Competency Definitions. IEEE Std 1484201-2007. 2008:1-32. Available from: http://dx.doi.org/10.1109/IEEESTD.2008.4445693.

[4] European Parliament, Council of the European Union. Decision (EU) 2018/646 of the European Parliament and of the Council of 18 April 2018 on a common framework for the provision of better services for skills and qualifications (Europass) and repealing Decision No 2241/2004/EC; 2018. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018D0646.

[5] Falbo RA. SABiO: Systematic Approach for Building Ontologies. In: Proc. 1st Joint Workshop ONTO.COM / ODISE. vol. 1301 of CEUR Workshop Proceedings. CEUR-WS.org; 2014. p. 1-14. Available from: https://ceur-ws.org/Vol-1301/ontocomodise2014_2.pdf.

[6] Guizzardi G, et al. Towards ontological foundations for conceptual modeling: The unified foundational ontology (UFO) story. Applied Ontology (Online). 2015;10:259-71.

[7] Calhau RF, Azevedo CLB, Almeida JPA. Towards Ontology-based Competence Modeling in Enterprise Architecture. In: 2021 IEEE 25th International EDOC Conference. IEEE; 2021. p. 71-81.

[8] Calhau RF, Almeida JPA. Zooming in on Competences in Ontology-Based Enterprise Architecture Modeling. In: Enterprise Design, Operations, and Computing. EDOC 2022 Workshops. vol. 466. Cham: Springer; 2023. p. 198-213.

[9] Calhau RF, Kokkula S, Cameron D, Guizzardi G, Almeida JPA. Modeling Competence Framework Elements with an Ontology-based Approach. In: 2023 IEEE 25th Conference on Business Informatics (CBI). IEEE; 2023. p. 1-10.

[10] Wood R, Power C. Aspects of the competence-performance distinction: Educational, psychological and measurement issues. Journal of Curriculum Studies. 1987 Sep;19(5):409-24.

[11] Miranda S, Orciuoli F, Loia V, et al. An ontology-based model for competence management. Data & Knowledge Engineering. 2017 Jan.

[12] Westera W. Competences in education: A confusion of tongues. J of Curriculum Studies. 2001;33(1).
[13] Draganidis F, Mentzas G. Competency based management: a review of systems and approaches. Inf Manag Comput Secur. 2006;14(1):51-64.
[14] Rodriguez D, et al. Developing competency models to promote integrated human resource practices. HR Management. 2002.
[15] Esposto A. Skill: An Elusive and Ambiguous Concept in Labour Market Studies. Aust Bull Labour. 2008.
[16] Paquette G. An Ontology and a Software Framework for Competency Modeling and Management. Educational Technology and Society. 2007;10(3):1-21.
[17] Rodrigues M, et al. A unified conceptual framework of tasks, skills and competences. JRC Working Papers Series; 2021.
[18] Brown JS. Learning in the digital age. In: The Internet and the university: Forum. vol. 71; 2001. p. 72.
[19] Maze JR. The concept of attitude. Inquiry. 1973 Jan;16(1-4):168-205.
[20] Altmann TK. Attitude: a concept analysis. In: Nursing forum. vol. 43. Wiley Online Library; 2008. .
[21] Guizzardi G. Ontological Foundations for Structural Conceptual Models. No. 15 in Telematica Instituut Fundamental Research Series. Enschede, The Netherlands: Telematica Instituut; 2005.
[22] Azevedo CLB, et al. An Ontology-Based Well-Founded Proposal for Modeling Resources and Capabilities in ArchiMate. In: 17th IEEE International EDOC Conference. IEEE; 2013. p. 39-48.
[23] Molnar G, Bradley N. Powers: A study in metaphysics. Clarendon Press; 2003.
[24] Guizzardi G, Wagner G. Towards Ontological Foundations for Agent Modelling Concepts Using the Unified Fundational Ontology (UFO). In: Agent-Oriented Information Systems II. Springer; 2005. .
[25] Arp R, Smith B, Spear AD. Building ontologies with basic formal ontology. MIT Press; 2015.
[26] Borgo S, et al. DOLCE: A descriptive ontology for linguistic and cognitive engineering. Applied ontology. 2022;17(1):45-69.
[27] Guarino N, et al. An overview of OntoClean. In: Handbook on ontologies; 2009. p. 201-20.
[28] Guizzardi G, et al. Types and taxonomic structures in conceptual modeling: A novel ontological theory and engineering support. Data & Knowledge Engineering. 2021;134:101891.
[29] Fonseca CM, Sales TP, Viola V, et al. Ontology-Driven Conceptual Modelling as a Service. vol. 2969 of CEUR Workshop Proceedings. CEUR-WS.org; 2021. Available from: https://ceur-ws.org/Vol-2969/paper29-FOMI.pdf.
[30] Almeida JPA, Guizzardi G, Sales TP, Falbo RA. gUFO: A Lightweight Implementation of the Unified Foundational Ontology (UFO); 2019. Available from: http://purl.org/nemo/doc/gufo.
[31] Barcelos PPF, et al. A FAIR Model Catalog for Ontology-Driven Conceptual Modeling Research. In: Conceptual Modeling. Cham: Springer; 2022. p. 3-17.
[32] Garijo D, et al. FOOPS!: An Ontology Pitfall Scanner for the FAIR Principles. In: ISWC 2021: Posters, Demos, and Industry Tracks. vol. 2980; 2021. .
[33] Tarasov V. Ontology-based Approach to Competence Profile Management. J Univers Comput Sci. 2012.
[34] Zaouga W, et al. Towards an Ontology Based-Approach for Human Resource Management. In: 10th Intl Conf Ambient Systems, Networks and Technologies. Elsevier; 2019. p. 417-24.
[35] Grant S, Young R. Concepts and Standardization in Areas Relating to Competence. In: Innovations in Organizational IT Specification and Standards Development. IGI Global; 2013. p. 264-80.
[36] Beverley J, Smith S, Diller M, Duncan WD, Zheng J, Judkins JW, et al. The Occupation Ontology (OccO): Building a Bridge between Global Occupational Standards. In: Proceedings of the Joint Ontology Workshops 2023 Episode IX: The Quebec Summer of Ontology co-located with the 13th International Conference on Formal Ontology in Information Systems (FOIS 2023), Sherbrooke, Québec, Canada, July 19-20, 2023. vol. 3637 of CEUR Workshop Proceedings. CEUR-WS.org; 2023. Available from: https://ceur-ws.org/Vol-3637/paper13.pdf.
[37] Sicilia MA. Ontology-based competency management: infrastructures for the knowledge intensive learning organization. In: Intelligent learning infra. for knowledge intensive organizations; 2005. .
[38] Braun S, et al. People Tagging and Ontology Maturing: Toward Collaborative Competence Management. In: From CSCW to Web 2.0. Springer London; 2010. p. 133-54.
[39] Fazel-Zarandi M, Fox MS. An ontology for skill and competency management. In: Formal Ontology in Information Systems. IOS Press; 2012. p. 89-102.
[40] Rezgui K, et al. Modeling Competencies in Competency-Based Learning: Classification and Cartography. In: 2018 JCCO: TICET-ICCA-GECO. IEEE; 2018. .