A Model for the Representation of Competences Applied to Student's Knowledge Modelling

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Abstract. A skill is a basic unit for cognitive processing that allows the use of concepts. A competence is the result of the application of a skill on a concept. Competences and their development play a central role in most educational and training programs. This paper presents a formal model for the representation of competences, called Competences Memory Map, an extension of the Memory Map [14], a model capable of representing knowledge in an integrated, simple and flexible way. The model is described using set theory through concept algebra and is computationally implementable. The formal description of algebraic and algorithmic operations over the model, as well as case studies, demonstrate that all the model properties hold as expected when dealing with complex real knowledge structures.

Keywords: Knowledge representation, Competences, Skills, Learning.

1 Introduction

Competences and their development have acquired a key role in many current teaching and training methods. The way of conceiving the processes of learning and teaching in most current educational models is based on the constructivist theory [6]. These models have become oriented towards the development of skills that can be applied in different contexts, i.e., the development of competences.
A competence is defined as the capacity of a person to use knowledge and skills in different situations either personal or professional [8]. The study of competences requires its analysis in terms of each of its components: knowledge and abilities, for the understanding of their whole functioning. There are different approaches to computationally model the process of learning, i.e., acquiring skills and knowledge and modelling them; among the most prominent models are OAR [16], The Knowledge Spaces Theory (KST) [4] and The Memory Map (MM) [14]. Several of the most relevant models for skills representation are: The Skills Theory [6], The Model of Skills Acquisition [1] and The ACT Model [2]. Between the most recognised models for the representation of competences, are: CbKST [3], The ELEKTRA Ontology Model [3] and The Competency Ontology [11].

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In this paper it is proposed a representation model of competences called Competences Memory Map (MM-Competences), a model capable to represent the components of a competence in an integrated and simple way, allowing also the modelling of the relationships between the elements of a competence and the structures created by the association of multiple competences. Section 2 presents a review of the basic elements involved in the model: concepts, skills and competences; Section 3 presents the model and its components; Section 4 presents the properties of the model; Section 5 describes the operations that can be performed within the model; Section 6 describes the competence structures forming process, and the distinctive properties and issues about the model. Finally, Section 7 presents conclusions and future work.

2 Concepts, Skills and Competences

2.1 Concepts

Knowledge is one of the two fundamental components of competences. It is defined according to O*NET as a collection of related facts, information and principles about a particular area that can be acquired through education and experience [10].
Knowledge has a fundamental unit of representation: the concept, without it, knowledge cannot be conceived nor represented. In Hobbes and Fodor works [14] the concept is conceived as the representation of a mental object and its attributes that can be manipulated and expressed symbolically through language.

2.2 Skills

Skill is the other fundamental element of a competence. 4ING [8] defines a skill as "an ability acquired by training that uses implicit memory to apply knowledge to standard situations and problems." On the other hand, in [14] Ramirez refers to cognitive skills as mental processes that interact with concepts through its application, with a given goal and with internal or external effects in the person who exercises it.
There are different models of representation of skills, as mentioned above in the introduction. One of the main properties of the skills is that they can be organised hierarchically according to their complexity, in terms of the cognitive processes used in their execution. A skill may require the use or mastering of another skill of less than or equal complexity. Some researchers propose taxonomies such as the O*NET Skills Taxonomy [10], Paquette's Taxonomy [12], Bloom's Taxonomy [7] and Revised Bloom's Taxonomy [7].

2.3 Competences

In order to define a computational model capable of representing competences, its associations and behaviour, these need to be analysed in terms of its basic components: the knowledge and the skills. There are many definitions of competence [3, 4, 8, 10, 11, 12, 13]. From a computational representation approach and based on the

definition of generic skills of Paquette [12] as "processes that act on the knowledge in a domain of application", competences are defined as declarations that can be demonstrated with the application of a generic skill to some knowledge, with a given performance. There are different models of competence representation, as mentioned above in the introduction.
The skills are generic cognitive processes that do not have a fixed hierarchy and complexity and guide the performance a task. Skills act on a given context and generate a competency when applied to the corresponding domain of knowledge. This is the reason why both, skills and concepts, are essential elements of competences.

3 The Competencies and Skills Memory Map

The MM-Competences is intended to model the mental state of a person in terms of his knowledge, skills and competences within a given domain. The operation of this model is based on the competences of a person and its computational representation through a unit called Competences-RU. This unit integrates knowledge, i.e., networks of concepts, and skills.
The MM-Competences Structure is formed by the set of competences developed by a person regarding a set of domains and the associations between them. A substructure of the MM-Competences determines the set of competences to apply in a given domain of knowledge to achieve a goal. This substructure is capable of modelling the sequence in which the competences are required through the associations between them. The MM-Competences is modelled as a directed graph where nodes are representing the competences and the arcs associations between them. The direction of the associations comes from general level competences to specific ones.

3.1 Concept Representation Unit

The Memory Map [14] fundamental unit is the Concept Representation Unit (Concepts-RU). Concepts-RUs operate as nodes of a dynamic and adaptable network. The Concepts-RU attributes are: Name, Identifier, Textual descriptions, Keywords and Concepts-RU Associations.
The Concepts-RU can be defined using set notation as the tuple:

$$c(A^c, A^{ccp}) \tag{1}$$

where A^c represents a set of all associations that Concepts-RU c has with other Concepts-RU, and A^{ccp} represents a set of all associations with Competences-RU in which c is a member. A^c and A^{ccp} are defined as follows:

$$A^c = \{a^c{}_1, a^c{}_2, a^c{}_3, \ldots, a^c{}_n\} \tag{2}$$

$$A^{ccp} = \{a^{ccp}{}_1, a^{ccp}{}_2, a^{ccp}{}_3, \ldots, a^{ccp}{}_n\} \tag{3}$$

where a^c represents an association between two Concepts-RU and a^{ccp} represents an association between a Concepts-RU and a Competences-RU.

3.2 Skills Representation Unit

A Skills-RU is defined by the attributes: Id, Label. A Skills-RU is defined using set notation as:

$$s(A^{cps}) \tag{4}$$

where s is the Skills-RU and A^{cps} is the set of all the associations of s with its corresponding Competences-RU. Given this, the set A^{cps} is defined as:

$$A^{cps} = \{a^{cps}{}_1, a^{cps}{}_2, a^{cps}{}_3, \ldots, a^{cps}{}_n\} \tag{5}$$

where a^{cps} represents an association between a Competences-RU and a Skills-RU.
There are multiple taxonomies that organise skills, all of them intend to be a reference for the use of the skills according to certain purposes or goals. A skill can be found in one or more levels of a taxonomy, according to their cognitive complexity, the skills can be grouped and ordered in a different way at the time of integrating a competency, since the complexity of a competency is determined by the complexity of the skill and the knowledge where it is used. However, hierarchies can be useful to organise the precedence of competences and skills in a learning process.

3.3 Competence Representation Unit

A Competences-RU associates, integrates and organise the tree types of units within an application context that can be measured and quantified, and is described by the following attributes: Id, Name, Description, Associated Concepts-RU, Skills-RU associations, Competences-RU associations. According to set notation a Competences-RU is defined as the following 3-tuple:

$$cp(c, A^{cps}, A^{cp}) \tag{6}$$

where cp is the Competences-RU, c is the Concepts-RU associated to cp, A^{cps} is a non-empty set of associations between cp and the Skills-RU that integrates it. A^{cp} is the non-empty set of associations between cp and another Competences-RU. The A^{cps} set corresponds to the definition given by expression 5, and A^{cp} is defined as follows:

$$A^{cp} = \{a^{cp}{}_1, a^{cp}{}_2, a^{cp}{}_3, \ldots, a^{cp}{}_n\} \tag{7}$$

where a^{cp} represents an association between two Competences-RU whose properties are described later. Fig. 1 shows the structure of a competency and its relationships with other elements of Memory Map.
The structure of concepts determines the domain of knowledge where a skill is used or applied; act that produces a competence. A Competences-RU acquires the domain of knowledge from its Concepts-RU associated, meanwhile a skill is generic, it can be used repeatedly to produce different competences. The number of different competences that can be produced is equivalent to the number of different contexts in a MM.

3.4 Associations

The attributes of the associations between Competences-RU are: Id, Competences Domain Structure identifier, Successor Competences-RU, Order, Role. An a^{cp} association between two Competences-RU is given by the 4-tuple:

$$a^{cp}(cp_{pre}, cp_{suc}, d^{cp}, r^{cp}) \tag{8}$$

where cp_{pre} is the predecessor Competences-RU and cp_{suc} is the successor Competences-RU of the association, d^{cp} is the domain of competences that owns the association, and r^{cp} is the role of the association. The directionality of the associations is determined by cp_{pre} and cp_{suc}, and indicates that cp_{suc} is a sub-competency of cp_{pre}.
On the other hand, the association between Competences-RU and Skills-RU have the following attributes: Id, Associated Competences-RU, Associated Skills-RU, Order. An association a^{cps} between one Competences-RU and one Skills-RU is defined as:

$$a^{cps}(cp, s, r^{s}) \tag{9}$$

where *cp* and *s* represent the Competences-RU and the Skills-RU, respectively, which are involved in the association, and r^{s} represents the role of the association.
The Skills-RUs can be associated in different ways to Competences-RUs. The *role* in the associations permits to establish these differences and treat each type of association in a different way. It has been identified two *roles* to associate a skill with a Competences-RU: Application and integration.

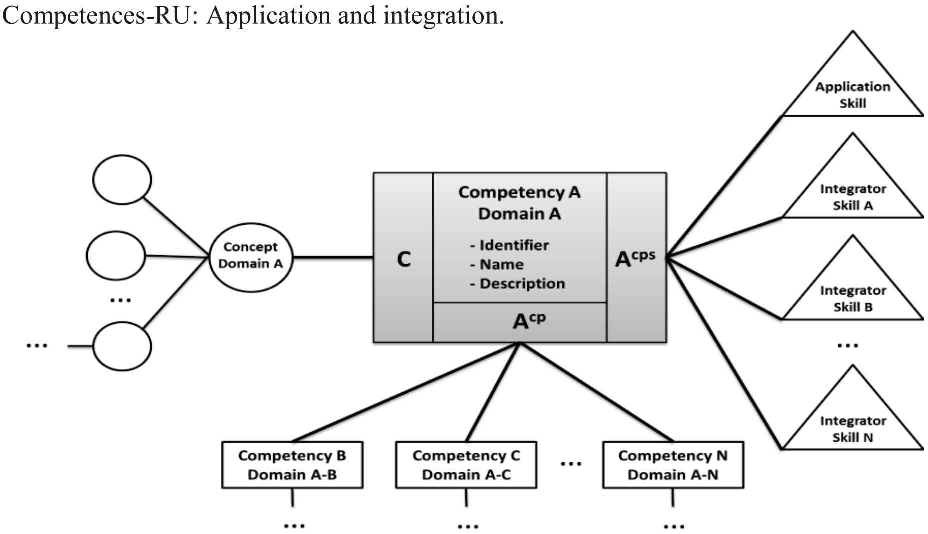

Fig. 1. Competency structure within the Memory Map.

The associations attributes between competences-RU and Concepts-RU are: Id, Associated Concepts-RU, Associated Competences-RU, Competence Domain. An association a^{ccp} between one Concepts-RU and one Competences-RU is defined as:

$$a^{ccp}(c, cp, d^{cp}) \tag{10}$$

where *c* is the Concepts-RU linked to the Competences-RU *cp* and d^{cp} is the Competence Domain defined by the relation between *c* and *cp*.

4 MM-Competences Properties

The highest level competence of a given structure determines the main goal of the whole structure, and the lowest or 'atomic' competences are similar to generic primitive skills. It has been identified three types of Competences-RU within the MM-Competences graph according to the nature of its associations: Root Nodes, Intermediate Nodes and Leaf Nodes, as seen in Fig. 2.

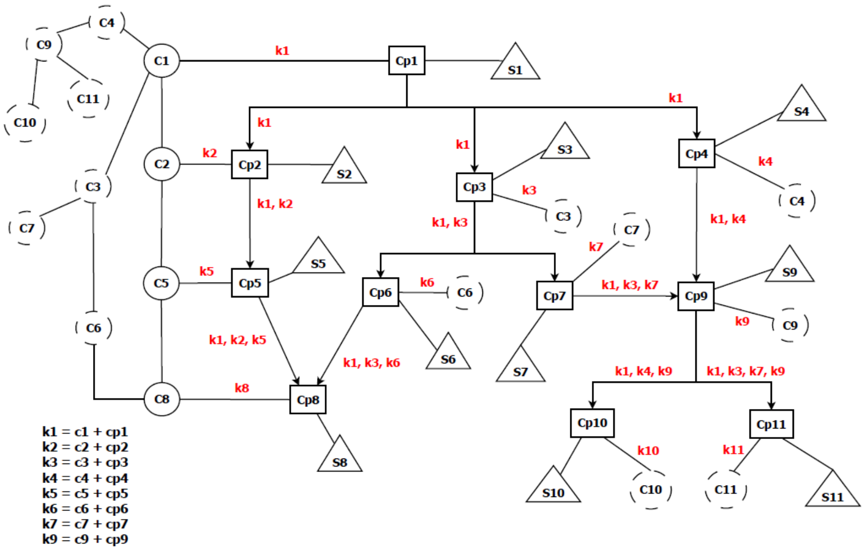

Fig. 2. Competence Domains generation and aggregation within the MM-Competences

Although the competences are aggregative and are organised hierarchically, the taxonomic structures formed by them are not fixed; on the contrary, they are dynamic, they are construed in terms of the present context. The associations are independent and can vary in terms of each attribute, including their direction, then, a Competences-RU can be the parent of another Competence-RU within a given structure and be its child in a different one; that is, they can reverse their hierarchical order in different structures corresponding to different domains of application. This dynamism in the relations created between competences comes from the existence of prior knowledge to the development of any competence.

4.1 Competence Domains

A Competence Domain originates from the association between a Competences-RU and a Concepts-RU, and represent the context for the development of a set of competences linked each other: a Competence Structure. Each association between a Competences-RU and a Concepts-RU creates a given Competence Domain which is propagated to all sub-competences of the related competences-RU, generating a Competence Structure. Competence Structures are aggregative, therefore, a Competence Structure can be a substructure of a larger one in a recursive way. This aggregative property is consistent with the aggregative nature of the knowledge in the brain, as the schools of constructivism propose. Fig. 2 shows the creation of Competence Domains and its aggregative property between Competences-RU for the formation of Competence Substructures. It also shows how a Competence Domain is generated through the associations between Concepts-RUs and Competences-RUs, and its propagation to the structures derived from the associations; it forms an aggregate of domains in each associations between the involved Competences-RU. The Concepts-RUs are represented by the circles, the Competences-RUs are represented by the rectangles and the Skills-RUs are represented by the triangles. Domains, highlighted in red, are represented by k_i.

5 MM-Competences Operations

MM-Competences, as part of the MM [14], has the goal of modelling the knowledge of a person or a machine in terms of competences, skills and concepts. To achieve this objective, the MM-Competences must have a set of operations that makes it functional and allows its manipulation. The Competences-RUs have the following general operations, which have been defined used set theory. There are also equivalent algorithmic definitions of the operations or inference processes, which are not presented here because of limitations of space.

Retrieving a Skills-RU. Let *cp* be a Competences-RU. According to the definition of a Competences-RU, *cp* can only be associated to a single application skill, a Skills-RU called *s*(*cp*) is defined as:

$$s(cp) = \{a^{cps}(s) | a^{cps}(cp) = cp\} \quad (11)$$

where $a^{cps} \in s(A^{cps})$ and there only exists a single a^{cph} such that $a^{cps}(cp) = cp$.
Retrieving a Concepts-RU. Let *c* be a Concept-RU. According to (6), there exists one Concepts-RU for every Competences-RU. The Concepts-RU *c*(*cp*) is given by:

$$c(cp) = cp(c) \quad (12)$$

where *cp* is the target competence. This means that even though *c* is a function of *cp*, it is only necessary to extract the Concept-RU from the definition of *cp* in order to obtain its value.

Retrieving Children Competences-RUs. Let *cp* be a Competences-RU. *cp* may require the execution of other Competences-RU, which are sub-competences of *cp*, in order to be achieved. The set of children Competences-RU of *cp* is given by:

$$U(cp) = \{a^{cp}(cp_{suc}) | a^{cp}(cp_{pre}) = cp\} \tag{13}$$

Where $a^{cp} \in cp(A^{cp})$, the set of all associations between *cp* and other Competences-RU, according to expression (7).

Retrieving Parent Competences-RUs. Let *cp* be a Competences-RU, *cp* may be required by a higher level Competences-RU in a structure of a given domain. The set of parent Competences-RUs of *cp* is given by the following relation:

$$U(cp) = \{a^{cp}(cp_{pre}) | a^{cp}(cp_{suc}) = cp\} \tag{14}$$

where $a^{cp} \in cp(A^{cp})$ and A^{cp} is defined as the set of all associations between *cp* and other Competences-RU's according to expression (7).

Retrieve the Competences-RU's associated to a Skills-RU. Let *s* be a Skills-RU, *s* is related to at least one Competences-RU; then the following relationship defines the set of all Competences-RU's *CP*(*s*) related to a single Skills-RU *s*:

$$CP(s) = \{a^{cps}(cp) | a^{cps}(s) = s\} \tag{15}$$

where a^{cps} is an association between a Competences-RU *cp* and a Skills-RU *s,* according to expression (9).

6 Discussion

A Competence Structure is a set of Competences-RU that are associated together to form a structure represented by a directed graph, with a root competency and a sequence. The elements derived from the root competency are the subcompetences necessary to master it. Subcompetence structures are defined recursively as needed and end when they reach the leaf nodes. The Competence Structures forming the MM-Competences can be manipulated as instances of it; this means that they preserve the properties of it and its operations. A Competence Structure is uniquely identified by the root competence and its domain, this identifier represents the *Competence Domain* of the structure. Competence Domains are aggregative and propagate from the root competence to the children competences. MM-Competences can be defined as the structure that integrates all competence domains of a given person or machine. As the domains are aggregative, the MM-Competences can be extended according to the learning progress, a property consistent with the aggregative nature of knowledge.

7 Conclusions and Future Work

It has been presented a representation model of competences. The MM-Competences is capable of representing the nature and behaviour of the competences and its elements: concepts and skills, in an integrated, consistent and flexible way, and com-

pletely supports the aggregative nature of the knowledge. Also, it was shown how the MM-Competences is capable of modelling the contextualisation of competences through its relation with sets of concepts and skills.
This model is intended to be used into educational applications for the modelling of student's knowledge, skills and competences, through a computational implementation in progress.

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