An Ontology-based Referencing of Actors, Operations and Resources in eLearning Systems

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Abstract

We explore some of the multiple relationships between two very active research fields in eLearning and Knowledge Management research: educational modeling languages and ontologies. Our previous research projects in the last 10 years have shown the central importance of the association between the learning activities and the knowledge and skills that they target. Studies on this relationship have led to the concept, we will present here, of a semantically referenced educational function grouping actors, operations and resources or learning objects. The referencing method proposed here is both qualitative (structured by an ontology) and quantitative, using a bi-dimensional skill/performance metric to situate the mastery level of knowledge associated to an actor, an operation or a resource in a multi-actor learning scenario.

Introduction. Functions are editable and executable graphic models representing multi-actor processes where activities are executed, using and producing resources. This editing process is similar to methods of task representation, flowchart or workflow modeling, and UML use cases and activities diagramming. When executed at run time, Functions facilitate the coordination of the participants who achieve the represented activities, using and producing resources (so-called "learning objects"). The representation of the cognitive processes involved while executing a Function Map demands the semantic referencing of its components: the operations (virtual or actual activities), the actors (abstracted or concretized by participants), the instruments (virtual or concretized by different kinds of resources).

In this communication a summary of our previous work will be outlined. Then we will present the concept of a Function Model, central to the LORNET project, as a generalisation of IMS-LD, a specification for the educational modeling of multi-actor activities. The third part will focus on ontology referencing of components in an eLearning Function Model and thus enabling eLearning systems to help users find persons, activities and resources that can enhance their knowledge and competencies. Then we will discuss the notion of competency equations to help improve the design, the support and the evaluation of learning activities.

1. Modeling Knowledge and Competency for eLearning

We will first briefly summarize our previous research on Instructional Engineering methodology, Educational Modeling Languages and Web-based eLearning delivery systems.

1.1 Central Instructional Engineering Operations

The fast evolution of learning technologies has multiplied the number of decisions one must make to create an eLearning system. While it is true that a majority of the first Web-based applications have been mostly ways to distribute information, more and more educators have become aware of the need to go beyond these simple uses of information and communication technologies. One of our contribution to this field has been to propose a new approach to Instructional Design (Merrill 1994), founded on cognitive science, labeled as "Instructional Engineering"; it is defined as: *"a methodology that supports the analysis, the design and the delivery planning of a learning system, integrating the concepts, the processes and the principles of instructional design, software engineering and cognitive engineering".* (Paquette 2003)

We have used a knowledge modeling approach to define such an instructional engineering method. This effort, started in 1992, and has led to the actual MISA 4.0 method (Paquette 2001) and to ADISA, a Web-based support system for designers using MISA. (Paquette, Rosca and al. 2001). In one of the main tasks, the instructional designer constructs the structure of the activities, a *network of Learning Events*. A second step in the elaboration of the instructional model is to build a *learning scenario* for each Learning Unit (task 320). A learning scenario is a multi-actor process model where the actors are involved into learning or support activities using and producing resources for themselves or other actors.

Prior or in parallel to that, the instructional designer will à built a Knowledge Model that is a graphic structured representation of the concept, procedures, principles and facts in the domain to be learnt. For this, a graphic modeling editor, MOT, is used, as a standalone or as a module of the ADISA Web-based design workbench. A companion task consists in defining entry and target skills and competencies for different types of learners, associated to some of the knowledge units in the domain model. A competency is a statement that a learner can apply a cognitive, socio-affective or psycho-motor skill to unit of knowledge at a certain degree of performance When the learning units have been defined, a sub-model of the domain model, with its linked competencies, is associated to each learning unit providing a knowledge representation of its content. Later on, when the learning scenarios are defined, other knowledge sub-models can be assigned to the learning resources, in each scenario, providing a knowledge representation of their content.

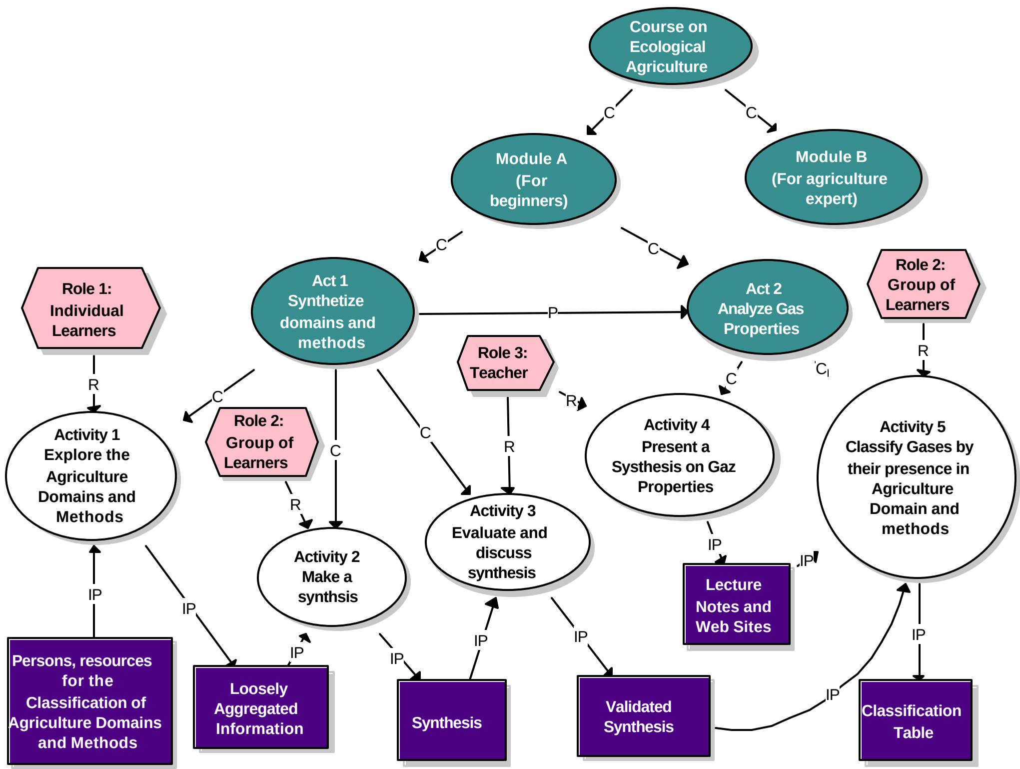
1.2 Adding Knowledge Representation to IMS-LD

The work on Educational Modeling Languages (Koper 2002, Rawlings et al 2002), and the subsequent integration of a subset in the IMS Learning Design Specification (IMS 2003), is the most important initiative to date, to integrate Instructional Design preoccupations in international standards (Wiley, 2002). It describes a formal way, and an XML binding that can be read by any compliant eLearning delivery system, to represent the structure of a *Unit of Learning* and the concept of a pedagogical *Method* specifying roles and activities that learners and support persons can play using learning objects.

The *learning Design* is composed of a method, learning objectives and prerequisites, and metadata referencing the unit-of-learning as in the IMS content packaging specification. The Method element and its sub-elements are central as they control the behavior of the unit-of-learning as a whole, coordinating the activities of the actors in the various roles and their use of resources. Like MISA's instructional model, it is a multilevel structure where altenative plays are decomposed in a series of one or more acts, each act being composed of one or more role-parts associating an actor to a single activity or an activity structure that can be decomposed further.

This IMS-LD Function on figure 1 is composed of two alternative plays, Module A and B, intended for different users. Only the first play is developed here, it contains two acts and 5 learning activities, ruled by individual learners or group of learners, and support activities by a teacher. Each couple Role/Activities correspond to IMS-LD role parts. Resources or learning objects link to activities (by IP links) are used or produced in the corresponding activities.

Figure 1 – An IMS-LD Method



While IMS-LD is a great progress in eLearning specifications, norms and standards, we believe it has to be expanded, first to a more general Function model that we will present in section 2, and also to associate knowledge and competencies to its components as we do in MISA. Actually, the only way to describe the knowledge in the activities or in the resources is to assign optional educational objectives and prerequisites, to the Unit of learning as a whole and/or to all or some of the learning and support activities. Objectives and prerequisites, although they correspond to entry and target competencies, are essentially unstructured pieces of text composed according to the IMS RDCEO specification (IMS 2002).

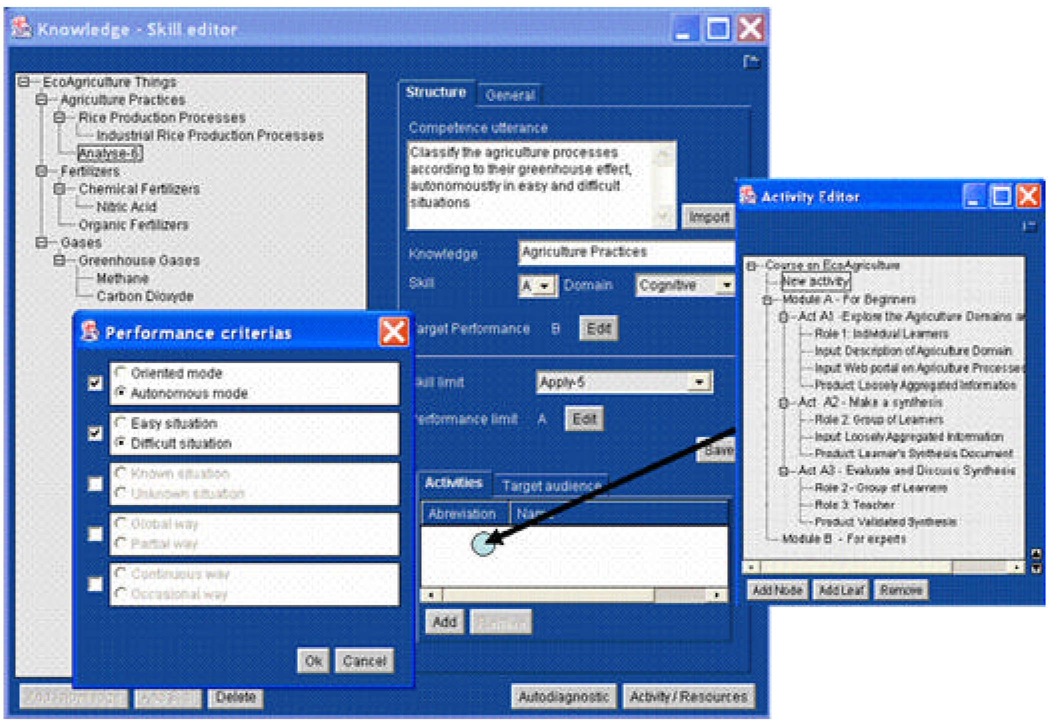
Unstructured texts are difficult to compare: consistency checking cannot be supported by a system between different levels of the LD structure, and even, at the same level, between the content of learning activities and resources, and the actors' competency. In fact, the content or learning resources is not described at all, and the actor's competencies are only indirectly defined by their participation in learning units or activities where educational objectives are associated. What we need is both a qualitative structural representation of knowledge in activities and resources, but also a quantitative one that can be provided by adding a metric to knowledge elements.

1.3 Adding Knowledge Representation Capabilities to a Delivery System

Without any representation of the knowledge to be processed in a eLearning environment, a delivery system will be unable to help its users according to their present and expected state of knowledge and competency acquisition. To expand the capacity of such systems, the Explor@-2 delivery system (Paquette 2001) has been based from its inception in on two structures, the instructional structure (corresponding to the learning design) and the knowledge/competency structure (corresponding to a domain ontology).

Figure 2 shows screens of the knowledge/competency editor provided to Explor@-2 designers. On the left, we see a hierarchy of concepts in the domain of ecological agriculture where the terminal nodes are skills associated to their parent nodes. If we select one of the skills (on the figure, "Analyze-6" is selected), plus some performance criteria (selected in the little window on the left), we can associate to its parent knowledge, here "Agriculture Processes", a target competency and an entry competency.

Figure 2 – A Knowledge and Competency Editor



Competency statements are texts that have a precise interpretation as knowledge/skill+performance couples. For example, the competency statement "classify the agriculture processes according to their greenhouse effect, autonomously in easy and difficult situations", is interpreted as analyze (skill level 6), autonomously in all situations (performance level B) to be applied to agriculture practices (knowledge). The skill and the performance levels form two ordered sets of value that enable comparison between competency statements for a certain knowledge. Performance levels A, B, C and D are derived from a combination of increasingly demanding performance criteria and can be transformed in numbers (A = 2, B = 4, C = 6 and D = 8) so as to obtain a metric enabling to represent the distance between entry and target competency for that knowledge (agriculture practice). This means that learners will stay at the "Analyze-6" level, with an expected increase of performance from A to B, that is from 6.2 to 6.4.

On figure 4, the lower right corner of the Knowledge/Skill editor is where the designer associates the selected knowledge/skill+performance)/ couples (the entry and target competency statements) to the components of the activity structure that has been built using the Explor@-2 activity editor. In this way, all the activities and the resources can be described by knowledge and competencies.

2. Function Models

There are limitations to the semantic referencing method we have just presented. The most important is that Explor@-2 do not support multi-actor processes and no competencies are assigned to actors except indirectly by competencies assigned to activity structure components. It is now our goal to both generalize the activity structure using a multi-actor workflows called Function Models, and also to reference later on, the actors, operations and resources in these Functions Maps, with Ontology components (for the knowledge part) and a competency metric.

2.1 Function Models as Multi-actor Workflows

A Function Model (or simply Function) within a eLearning system is composed of actors playing a role in activities (or operations) where they use and produce resources for themselves or other actors (Paquette and Rosca 2002). From a computer science view, a Function Model corresponds to a use case (Bosch et al. 2001) of that system. From a conceptual point of view, in a biological or ecological sense, a function is a particular physiology, an interesting subsystem of operations within of the learning system organism. Particular cases are instructional scenarios, delivery models and IMS-LD methods.

For example in a delivery model, learners are work colleagues can use an electronic performance support system (EPSS) offering integrated training and work activities. They would equipped with the same databases, documents, and tools as those used at work. These organizational resources are provided and supported by the workplace technicians. The learners acquire knowledge and competencies by solving problems similar to those experienced in the workplace. Learners use hyperguides that provide activity assignments to be completed with the training material published on the Internet. The learning material is created and maintained by the training organization designers. The target competencies are validated though various exercises and tests. A trainer-manager supervises the learners' work and training by providing advice and assessing their work and knowledge, skills and competency progress. All these operations can be represented as a multi-actor workflow where the different actors rule operations where the use resources and produce resources for other actors or with other actors.

2.2 Embedding Knowledge and Competency in a Function Model

We obviously need a unique ***semantic referential*** (for knowledge and competencies) for all the components of a Function that must reach competence equilibrium in a given domain. For example, if a learning activity, to be achieved, requires a level of mastery of certain knowledge, then the resources provided to the learner (persons, documents and tools) must enable the learner to progress from a lower entry mastery level to the one required by the activity.

But if we use only a knowledge referential without précising the mastering level, we obtain a coarse granulation of sense and, as a consequence, weak semantic management services. We need measures of a knowledge mastering, a weighted ability defined on that knowledge. We can use different mastering scales: simple quantitative 1-10, Bloom taxonomy, combinations between skills taxonomies and performance level as in MISA, etc. It would be preferable that the level scale that describes the mastering of any knowledge be reasonably simplified, to be manageable. Still, the levels must correspond to clearly identify cognitive processes such as memorizing, applying, analysis, synthesizing or evaluating knowledge (Paquette 1999). The evolution of a learner on a competence scale materializes a learning process: therefore, it should be managed explicitly and expressively.

Figure 3 – A Skill/Performance Scale

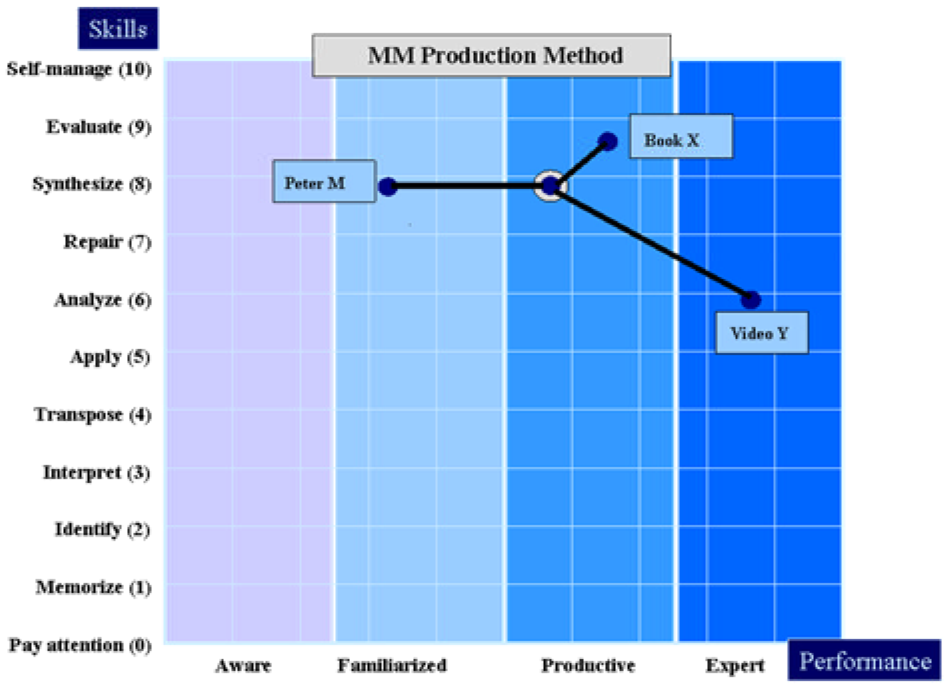


Figure 3 presents such a competency scale that is used in the Explor@ knowledge/activity editor presented above. It has also proved a solid tool for instructional engineering projects using the MISA method. Here the mastery of a knowledge term, Multimedia Production Method, is evaluated on bi-dimensional scale. The skills scale, from 0 to 10, is complemented by a performance scale, where values are decimals from 0 to 0.9, corresponding to qualitative terms like "Aware", "Familiarized", "Productive" or "Expert". On the figure, we see that PeterM's knowledge is evaluated at 8.3: he can synthesize MM production methods, at a performance level showing he his familiarized with synthesizing such procedures. On the other hand, Book X is evaluated near 9.7; that might be too much for the actual competency of PeterM, unless we aim a target competency at that level or higher. On the other hand, a lecture on VideoY is evaluated near 6.9 so it is below PeterM's actual competency and might not prove very useful, except maybe as a review.

The knowledge space of a domain can also be structured in many ways: dictionaries, thesaurus, book summary, library catalog, indexes and metadata, knowledge graphs, ontologies, etc. The tree organization of the knowledge referential seems an important aspect because it allows the competence inheritance of a parent node to his children, if these have no other explicit specifications. This can reduce significantly the mechanisms of competence analysis and management. But the tree organization is two restrictive for describing the rich network of relations that ties the concept structures. A relational (predicate) logic must then complete the concept tree and sustain more refined mechanism of conceptual matching.

These requirements suggest that a good candidate for the semantic indexing of the function components will be a combination between domain ontologies (Davies et al 2003, Breuker et al 1999) and a simple and operational competency scale.

3. Ontology Referencing of a Function Model

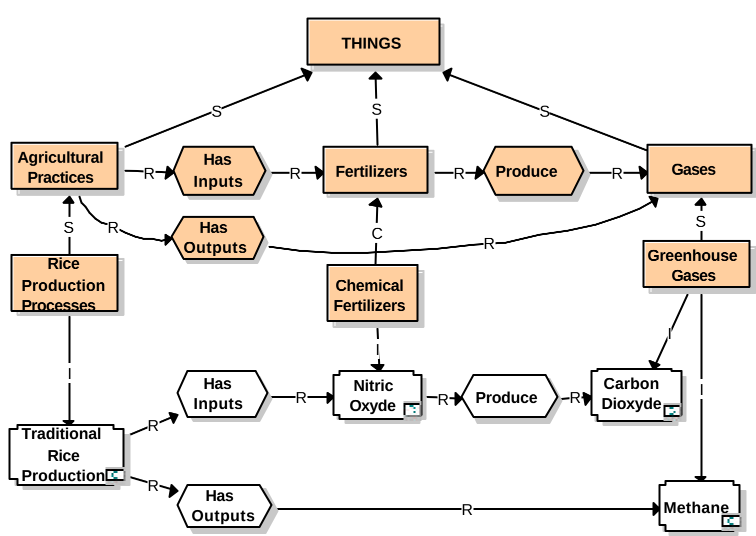
In the TELOS architecture framework we are developing in the LORNET[1] project, the construction of a domain ontology and its use for referencing actors, operations and resources represented in a Function, is central. It is in continuity with the work presented in section 1. We present here a tool and a process to integrate qualitative and quantitative ontology referencing in a Function Model.

3.1 Construction of a Domain Ontology

Some technologies and methods to develop the Semantic Web are now becoming mature. On February 10, 2004, the World Wide Web Committee has issued a recommendation for the definition of a standard Ontology Web Language: *"OWL is a revision of the DAML+OIL web ontology language incorporating lessons learned from the design and application of DAML+OIL."* (W3C, 2004)

Many ontology engineering methods exists such as the one presented in (Sure and Studer 2003). We present here, as an example, an ontology aiming to identify Agriculture practices that influence the greenhouse effect. A function model (such as the IMS-LD method presented on figure 1) describes the use of the ontology to find out agriculture alternative practices, in at least five agriculture domains, and to build a transition plan towards the replacement of the old practices by the more ecological ones. The ontology would serve in a browsing mode to access related resources and to launch search agents to find persons, information resources and learning activities useful to solve the problems.

Figure 4 – A Simple Ontology



[1] LORNET (Learning Objects Repository Networks) is a pan-Canadian research network involved in Semantic Web applications to eLearning and Knowledge Management systems led by one of the authors

Figure 4 presents a simple example to illustrate the use of the MOT+ knowledge editor, used in MISA, as a graphic tool for Ontology Engineering[2]. The upper part of the graph presents the top levels of three hierarchies of concepts (linked by sub-class links "S"): *agricultural practices*, *fertilizers* and *gases*. Some properties of these concepts are shown on the graph. An Agriculture practice, such as Rice Production Processes, *has inputs* including fertilizers and *outputs* that can be gases. Fertilizers can also *produce* gases, some of which are *greenhouse gases*. Figure 4 also shows a few of the instances that will constitute the knowledge base. Here, we see an agriculture practice, *Traditional Rice Production*, having among its outputs *methane gas*. It also has *Nitric Oxide* amongst its inputs, a chemical fertilizer that produces *Carbon Dioxide*. Both of these gases are example of *greenhouses gases* harmful to the environment.

We can now proceed to reference the components of the Function Model presented on figure 5. For this, sub-graphs of figure 4 are associated to actors, acts and activities (operations) and resources used and produced by the activities.

3.2 Competency equations

We will now use the skill/performance scale presented above to show how we can add a metric to represent the mastery of knowledge terms that have been associated to operations, actors and resources of the IMS-LD scenario (or function) presented on figure 1.

Figure 5 – Associating knowledge mastery values to scenario components

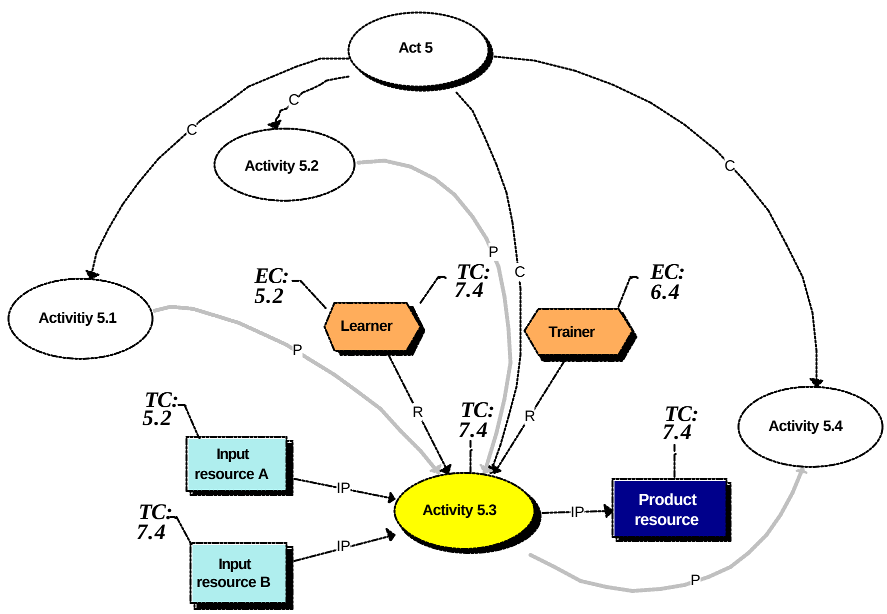


Figure 5 shows part of a learning design where Act 5 is composed of four activities. Activity 5.1 and 5.2, preceding Activity 5.3, itself preceding Activity 5.4. Let us focus on activity 5.3, an operation performed by a learner and a trainer, both interacting with input resources A and B, helping the learner produce a certain resource.

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[2] We are actually working towards having MOT+ produce automatically a standard OWL description of an application domain instead of its actual XML schema

On this figure, we see that for a certain knowledge term in the ontology, for example “rice production processes”, the target competency (TC) of activity 5.3 is evaluated at a 7.4 level (skill: “Repair”, performance: B) on the skills/performance scale. Then the produced resource (an exam, an essay, a classification table,….) should show a TC level equal or higher than 7.4.

Since the learner has an entry competency (EC) of 5.2 (skill: “Apply”, performance A), he needs help. Here we have a trainer with EC = 6.4 so he alone cannot bring the learner all the way up, but he can certainly help him fill part of the gap. Also, the learner can use two input resources. Resource A is at TC=5.2 so it can only serve to test the entry competencies of the learner, to make sure he has the prerequisites. Fortunately, Resource B has a TC = 7.4, the right target, but lets hope it not a lecture that starts at 7.4, but maybe an aggregate of learning objects that can help him progress with the help of the trainer. By the way the trainer will also learn a little bit in the process, so at the end the activity, we could consider raising his EC for the next run of the activity.

There are many other situations to investigate where competency equations such as these will prove useful, but this example shows that this kind of analysis, by humans, by machines or both, can bring more intelligence in learning environments before learning takes places (at design time), during learning (to help learners use available resources adequately) and after learning (to evaluate and improve designs).

Conclusion

By definition, domain ontologies are continuously evolving in the semantic Web. Furthermore, in communities of practice and project-based learning, the learners themselves can be the ones who will make the ontology evolve. This is why it is important to lower the barrier to ontology construction and referencing, taking in account that ontologies are a moving target. To achieve this, more user friendly graphic tools will have to be designed.

On a more theoretical level, the maintenance of the coherence of the Ontology through versioning by different actors is a huge problem researchers have just started to address. Our approach here is to classify the possible changes from a version to a subsequent one and to provide a tool that will assist the Ontology designer (Rogozan and Paquette, 2004) in the different cases that can occur.

Finally, the knowledge referencing of Functions or multi-actor workflows using an ontology needs to be complemented by a knowledge mastery metric such as the one proposed here. This important aspect will be further investigated to better understand the multiple possible configurations.

The Semantic Web and its associated technologies and methods are recent developments that have barely begun to be used in applications. Extensive solution-oriented applied research in knowledge engineering and distributed computing is needed to adapt, integrate and evolve these technologies, and to produce a framework for building and using learning object (or resource) repositories on the Web, for knowledge management and learning.

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