A Competency-Based Ontology for Learning Design Repositories

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Abstract—**Learning designs are central resources for educational environments because they provide the organizational structure of learning activities; they are concrete instructional methods. We characterize each learning design by the competencies they target. We define competencies at the meta-knowledge level, as generic processes acting on domain-specific knowledge. We summarize a functional taxonomy of generic skills that draws upon three fields of knowledge: education, software engineering and artificial intelligence. This taxonomy provides the backbone of an ontology for learning designs, enabling the creation of a library of learning designs based on their cognitive and meta-cognitive properties.**

Keywords*—*Learning Designs; Learning Objects Repository; Competency Referencin; Generic skills; Learning Design Ontology; Metadata for Learning Designs

I. INTRODUCTION

A search on the Internet reveals the importance given to competency-based learning and training [12]. Ministries of education, school boards and teacher training institutes use competency profiles to define school programs or required qualities from the teachers, especially in the use of technologies in education. Consulting companies present their expertise by enumerating competencies, marketing their services in this way. Other companies offer services or computerized tools to help their prospective customers define or manage the competence of their staff, looked upon as the main asset of an organization in a knowledge management perspective. Governmental agencies or professional associations use competency-based approaches to define conditions to the exercise of a profession and to plan their vocational training programs.

In the IMS-RDCEO specification [9], competencies are expressed as simple natural language sentences that state informally that a group of person has the “capacity” or the “knowledge” to do certain things. Competency profiles are in general loosely structured collections of such texts that are not always easy to interpret, communicate or use.

In our previous work [20,22,23] on the MISA Instructional Design method for eLearning, we have defined a structural definition for competencies using knowledge representation techniques. This definition is based on the interrelation of a meta-knowledge domain, where generic skills are described, and knowledge in an application domain to which generic skills are applied. Here we use the word “knowledge”, not as a synonym for “concept”, but for any intellectual structure (concept, procedure, principle, taxonomy, decision tree, sets of facts, etc.) that can be processed by a cognitive system.

In section II, we summarize the main elements of this competency model and its relation to other generic skills’ taxonomies proposed in various fields. In section III, we define the backbone of a learning design ontology based on competencies and the generic skill component of a competency. In section IV, we develop an RDFS vocabulary to reference learning designs with a set of metadata that can be used to search and retrieve learning design from a repository of learning design objects.

II. COMPETENCIES AND LEARNING DESIGNS

This section summarizes the basis of a competency definition and its relation to learning designs.

A. Generic skills: integrating many views in a taxonomy

In order to solve classification, diagnosis or construction problems for example, it is necessary to mobilize corresponding classification, diagnosis or construction generic skills. Competencies can be defined by associating generic skills to some knowledge it can be applied to, demonstrating that this actor is able to solve a corresponding class of problems.

This first view sees generic skills as generic problem solving processes. The area of generic problems or tasks draws on the software engineering work of authors like by Chandrasekaran [9]**,** McDermott [16], Steels [29] and Scheiber et al, 1993 [28]. Our generic skill taxonomy expand these various taxonomies.

Another view defines generic skills as active procedural meta-knowledge that can be applied to various knowledge domains. Procedural meta-knowledge is implicit in the work of researcher in science epistemology such as Thayse [30] , Popper [9] and Pitrat [24,25]. We make it explicit in the proposed generic skill’s taxonomy.

A third view on generic skills is to be found in taxonomies of educational objectives elaborated by researchers in educational technology such as Bloom [3], Krathwohl et al [3], Romisowski [27], Gagné [7] and Merrill [17]. Our taxonomy integrates and extends these taxonomies.

B. Competency as generic skill applied to knowledge

Integrating these viewpoints leads us to a structural definition of the notion of competency, as procedural meta-knowledge applied to specific knowledge. Romisowki [27] has expressed very well the simultaneous acquisition of knowledge and meta-knowledge in the learning process: « The learner follows two kinds of objectives at the same time - learning specific new knowledge and learning to better analyze what he already knows, to restructure knowledge, to validate new ideas and formulate new knowledge ». This idea has been expressed concisely by Pitrat [24]: « meta-knowledge is being created at the same time as knowledge ». This is the essence of the notion of competency we are defining here.

This notion of competency, as a *generic skill applied to knowledge in an application domain* fits well also within the framework of action theory Bélisle et Linard [2], based on the work of cognitive science authors such as Vygotsky, Leontiev, Piaget, Searle and Bruner. The association between generic skills, seen as generic cognitive processes, and specific knowledge avoids an artificial separation between knowledge and know-how, integrating cognitive and meta-cognitive aspects that must be present together for thoughtful human action and learning.

This discussion leads us to a representation of competencies, as an association between a generic skill, to be represented graphically as a process model in a meta-knowledge domain, in relation to domain specific knowledge, also represented by a knowledge model.

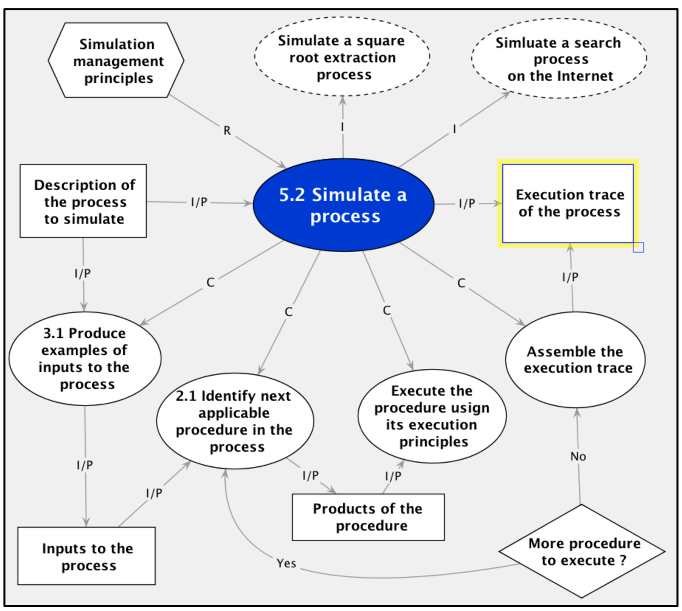

Fig. 1. Example of a generic skill model: Simulate a process

In many applications we have used the MOT graphic language [23] to represent both models. Figure 1 shows one example of generic skill, a simulation meta-process, that can be applied (through instantiation) to many specific process such as "Search the Internet" or "Extract a square root". The instantiated simulation process, *Simulate a search process on the internet*, provides the link between the meta-model and the application model (Internet processes), thus defining a competency: *to be able to simulate a search process on the Internet*. Figure 1 presents the input and output of the meta-process "Simulate a process", together with its component subprocesses. Numbers refer to the generic skills in the taxonomy shown later in table I.

C. *Competencies and learning designs*

Now suppose we wish to design a course module to help a learner learn a process such as searching the Internet, or in another domain, a process to extract square roots. A good idea would be to use the simulation generic skill process model as a template. To do this, the main subprocesses of the simulation meta-process are transformed into learning activities. Then a second step is to instanciate the template with terms in the application domain, with Internet search terms or arithmetics terms.

The LD template derived from the generic process on figure 1 would contain at first the following learning activities.

- Activity 1: Consult the description of the process to be simulated and produce inputs to the process;
- Activity 2: Select an applicable procesdure (or task) in the process;
- Activity 3: Execute the selected task and produce its outputs;
- Activity 4: Check if the process is completed; if not, select an applicable procedure, repeat 2, 3 and 4; if completed, report excution trace and final output.

Then instatiating this LD template to the Internet search domain would provide the following learning design assignments.

- Activity 1: Read the Internet search process provided by the instructor on the course Web site and select possible search requests you could make;
- Activity 2: Select a request to search the internet;
- Activity 3: Build and execute a search request to produce a list of Web pages;
- Activity 4: Is the result satisfactory ? ; if not, refine the search request and repeat 2, 3 and 4; if completed, report list of steps and final list of Web pages.

The important thing here is that the generic process provides the backbone of the learner's assignments in a learning design. In that way, we make sure that the learner exercises the right generic skill, here simulating a process, while working on the specific knowledge domain, thus building specific domain knowledge and meta-knowledge at the same time.

Other components of a generic skill model can also help choose the kind of learner assistance activities. For example, generic execution principles of procedures in the model could help a facilitator guide some learners who have difficulties with corresponding activities in the LD scenario.

III. AN ONTOLOGY OF LEARNING DESIGNS

A taxonomy of generic skills is here presented. It provides the backbone for an ontology of learning designs and, later on a set of metadata element for a repository of learning designs.

A. *The taxonomy of generic skills*

The taxonomy shown on Table 1 has matured through a long experimental process combined with Instructional Engineering tool building. A first version, close to Bloom's taxonomy was elaborate in 1993, integrated in the AGD instructional design support system and expanded within the various versions of the MISA method [18,19,20]. It has been used with experts in many organizations and was field-tested in various applications, in particular to build a complete program for professional training.

TABLE I. GENERIC SKILLS' TAXONOMY

Generic Skills Taxonomy Layers		
1	2	3
Receive	1. Pay Attention	
	2. Integrate	2.1 Identify 2.2 Memorize
Reproduce	3. Instantiate / Specify	3.1 Illustrate 3.2 Discriminate 3.3 Explicitate
	4. Transpose/ Translate	
	5. Apply	5.1 Use 5.2 Simulate
Create	6. Analyze	6.1 Deduce 6.2 Classify 6.3 Predict 6.4 Diagnose
	7. Repair	
	8. Synthesize	8.1 Induce 8.2 Plan 8.3 Model/ Construct
Re-invest	9. Evaluate	
	10. Self-manage	10.1 Influence 10.2 Self-control

The taxonomy expands on three layers from left to right, from the more general skills to more specific skills. The first layer groups four general information processing processes. The Second layer includes ten generic skills that can be found in educational objective taxonomies or software engineering problem types like those in KADS [4, 8], The third layer corresponds to more specialized skills that are widely used in instructional design methodology. We have described in [19] each of the generic skills in this taxonomy by its inputs and its products and by a detailed generic process such as the one presented on figure 1 for the *5.2 simulate* process.

It is possible to extend this specialization hierarchy to more layers. From layer to layer, we get more and more specialized generic skills until every aspect is totally instantiated in a particular application domain. If we go down the following chain: Create – Analyze – Diagnose – Diagnose a biological problem – Diagnose a human heart problem, at a certain point, the skill is no more generic. It becomes procedural knowledge within a specific knowledge domain.

The question whether generic skills are ordered from simple to complex is a delicate one. For generic skills in the first layer, it is quite straightforward: reception skills involves only attention and memory operations, needed at the other levels as well; reproduction skills are essentially instantiation operations from more general knowledge; creation skills produce new knowledge from more specialized ones, involving also some reproduction operations as components; and, finally, re-investment skills involve the explicit use of meta-concepts to evaluate and control the use of knowledge, thus embedding all other reception, reproduction and creation skills as components.

A simple-to-complex relation between two generic skills can be defined in the following way: A generic skill A is aid to be simpler than a generic skill B if the generic process representing A appears as a sub-process or an operation within the model of the generic process B. For example, to synthesize knowledge, we need to analyze components several times before we can combine them in creative ways, so analysis is simpler than synthesis according to this definition.

We have constructed process graphs for all the generic skills in layer 2, providing a validation of their simple-to-complex ordering. In addition, experimental studies with learners made by Martin and Briggs [15] have also validated partly this ordering hypothesis in the case of taxonomies for learning objectives in the cognitive domain [3] and in the emotional domain [13]. Both are embedded the generic skills' taxonomy on Table 1.

B. *Backbone of a learning design ontology*

Usign the MOT modeling software, we present the backbone of learning design ontology, corresponding to the generic skills' taxonomy presented on table 1.

The nodes of the model on figure 2 represent classes of learning designs. The specialization links (in black) between LD classes goes from right to left , while the simple-to-complex links go from top to bottom. We do not extend the simple-to-complex relation at the third layer of the generic skill's taxonomy because there is no evidence that would validate this relation. For example, a classification LD is neither simpler nor more complex than a diagnosis LD; both are just two brands of analysis LD.

C. *Specializing further the generic skills and LD templates*

The MOT software enables the association of submodels to any object in a graph such as the one on figure 2. Figure 3 shows such a submodel for the diagnosis LD class. This can be done also for any node in the graph on figure 2.

The graph on figure 3 presents three sets of diagnosis subclasses, each presenting orthogonal ways to specialize this LD class: according to the knowledge type, the required performance level and types of inputs in the process.

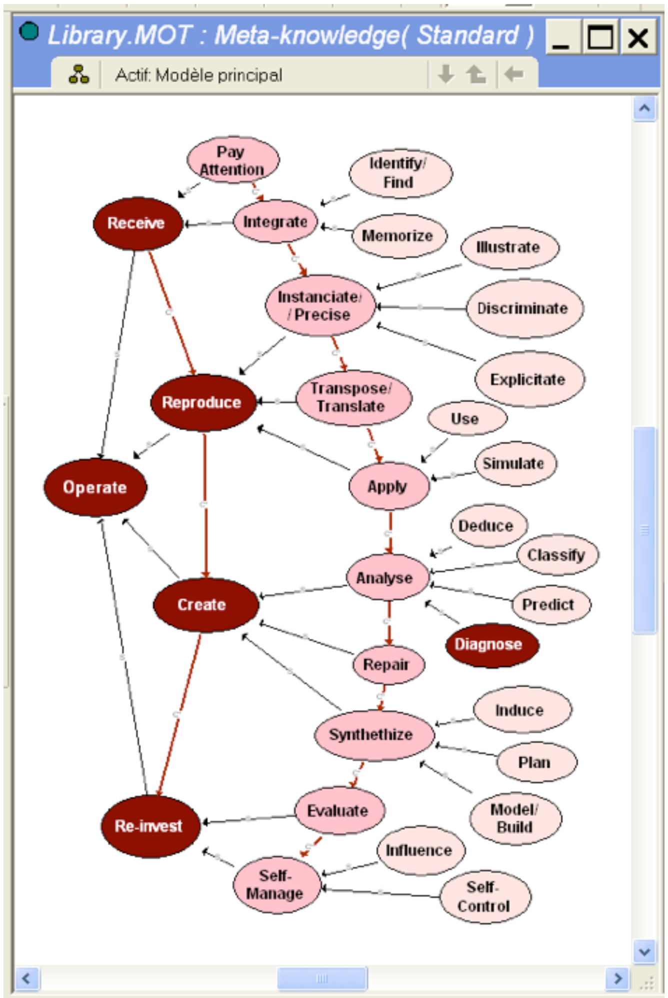

Fig. 2. Specialization and complexity links in the LD taxonomy

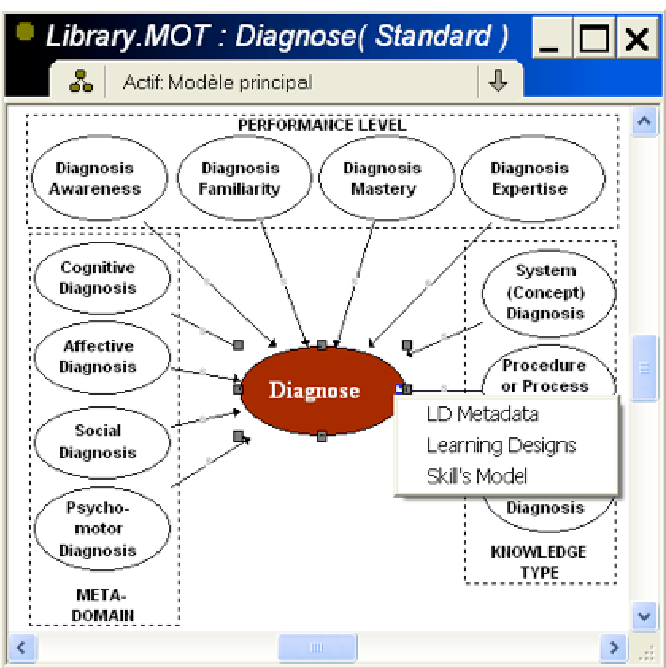

Fig. 3. Sub-classes of a LD class: the Diagnosis LD template

D. Knowledge type

The set of alternative diagnosis sub-classes on the right side of figure 3 refers to the type of knowledge objects in the application domains that are to be processed by the generic skill. For example, diagnosis processes for a system of components, or for a procedure, or for a rule-based system are all specializations of the general diagnosis process. The first one will attempt to generate and test components of the system; the second one will verify if the procedure outputs the expected results for different inputs, and the third one will check if the rules are consistent and cover all main cases. Theses situations refer to taxonomy of knowledge types and models such as the one presented in [23].

E. Performance level

The upper set of diagnosis sub-classes on figure 4 refers to the performance level to be deployed when performing a diagnosis. Combining attributes like reliability, complexity, autonomy and familiarity, we define performance class such as the ones on the figure. For example, if a person can perform a diagnosis only on certain occasions (unreliability), in simple and familiar cases, and with outside support, the performance level could be classified as very low skilled diagnosis or simple diagnosis awareness. The LD template should be modeled accordingly. At the other end of the spectrum, if the process is performed in a reliable way, autonomously, in complex as well as new situations, then the diagnose skill should be modeled as "expert diagnosis"

F. Cognitive, affective, social and psychomotor meta-domains

The left set of diagnosis sub-classes is based on the types of inputs and outputs of the diagnosis process. Are they of a cognitive, affective, social or psychomotor nature? These four meta-domains provide another way to specialize a generic skill or a LD template. This deserves more detailed explanations.

For example, the generic diagnosis process takes a component model of a situation as its input and returns a list of faulty elements. The diagnosis proceeds in such a way that a component is selected to check if it contains a faulty component. Then this component is decomposed into sub-components to find other hypothesis for faulty components. Each component is tested; its attributes are compared to some norm. If the component is faulty, it is added to the list; if not, a new hypothesis is generated and tested.

This generic process can be applied in various application domains, for example to diagnose a hardware system or to diagnose an emotional situation in a group. The difference between the two applications is the nature of the input and output of the diagnosis process. In the first case, it is applied to a model of a hardware system with components being pieces of equipment down to very small parts that can be deficient; the output is a list of faulty parts. In the second case, it is applied to an affective situation where the components are facts and opinions that people have expressed on a certain event that has caused guilt to occur in a person; the results can be acts that should not have been made, or opinions that are clearly misled.

In [19], we have built a complete table showing examples in the cognitive, affective, social and psychomotor meta-domains for each of the 10 generic skills on the second layer of our taxonomy. It shows that this taxonomy can be used in each of the four meta-domains.

This work underlines that generic skills and LD templates are characterized by the operations they perform on some input, rather than according to the type of stimulus or response, whether they are cognitive acts, motor actions, affective or social attitudes. We are not claiming here any psychological theory on knowledge, skill and attitudes. Only that at a certain abstraction level, the same generic process can be applied to knowledge, action or socio-affective attitudes. We are claiming operational usefulness, not psychological truth.

We propose that in instructional engineering, it is important to integrate the meta-domains in the same framework. As underlined by Martin and Briggs *"This subdivision (between meta-domains) is relatively arbitrary because the psychologists and the educators agree that, in the reality of educational practice, no real separation between the cognitive, emotional and psychomotor states is possible.* [15] " Martin and Briggs quote in support to this assertion several other authors, notably some having produced important taxonomies for educational objectives such as Bloom [3] and Gagné [7].

IV. Metadata for a Repository of LD Objects

Competencies provide the backbone for a learning design ontology templates and examples. They also provide a set of key metadata elements to describe LD objects. These metadata elements enable the construction of LD repositories where LD classes and subclasses, as well as instances (concrete learning scenarios) can be stored, search and retrieved to support the instructional engineering processes. Malone et al. [14] have proposed a similar repository for business processes.

A. Repositories of LD objects

While working on documents to support the use of Educational Modeling Languages and the IMS Learning Design specification [10], we have underlined that "to support the reusability of good learning designs, it is essential that libraries of learning designs be made available as learning objects in one or more repositories" [21].

We proposed that the learning object repositories under construction in different countries should distinguish between "content object", "tool objects" and "process objects", the latter including generic and specific learning designs (or scenarios). Then a growing library of these learning designs could be reused and instantiated to particular knowledge domains. New learning design templates could be built by abstracting generic processes from the large body of existing scenarios, describing the learning material by generic principles or generic descriptions of learning resources, situating the resulting abstraction in the framework of a LD ontology.

We have applied these principles to build some learning design repositories. The first one was built using the IEEE Learning object metadata (LOM) specification. Figure 4 shows part of the repository in the PALOMA metadata editor and research tool. It shows a list of folders grouping learning designs, one of them selected with its LOM record on the rightmost side of the figure.

A display of the taxonomy on figure 4 has been integrated in the LOM classification field enabling users to choose which generic skill could best describes the learning design. Other classifications can be included to select the type of knowledge, the meta-domain or the instructional strategy or delivery mode. Once learning designs have been referenced with such metadata, the repository can be queried with the classification entries in different ways to find LD objects according to the corresponding attributes.

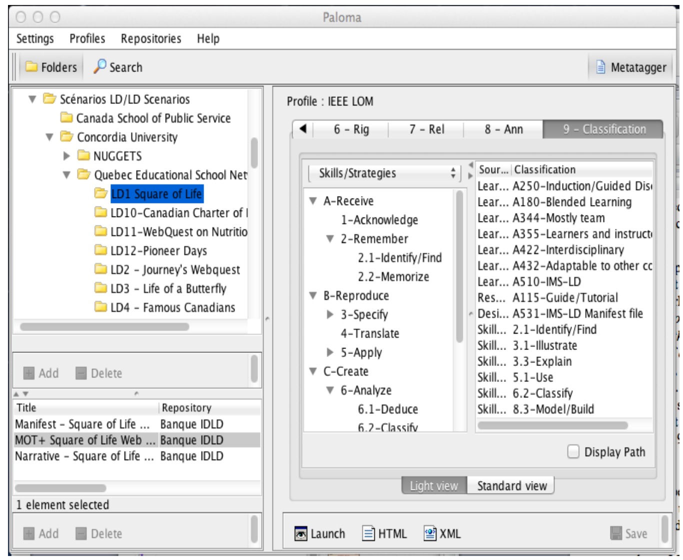

Fig. 4. A LD repository – LD referenced using skill's Taxonomy

Such a repository can be used to register and retreive LDs using the LD taxonomy metadata. Figure 5 shows a class of LDs and eleven instances that were produced and referenced in the repository during a decomposition/aggregation process. This process was applied to an existing course on Artificial Intelligence labelled Inf-5100. The numbers on the figure show the order of operations in the process.

- (1) The INF-5100 course (level 3 in the LOM specification) was first modeled, referenced and integrated in the LD repository.
- (2) Using the MOT+LD graphic editor, the model was stripped of its content by deleting all content resources to obtain a level 3 pattern , also added to the repository.
- This pattern was then decomposed into five level 2 modular patterns, each added to the repository.
- (4) Using these level 2 patterns as activity structures, a new level 3 pattern (Course X) was aggregated and added to the repository.
- (5) Content items have been added to this level 3 pattern to obtain a new level 3 course in a completely different subject, such as political science, but using the same scenario structure as the initial course.

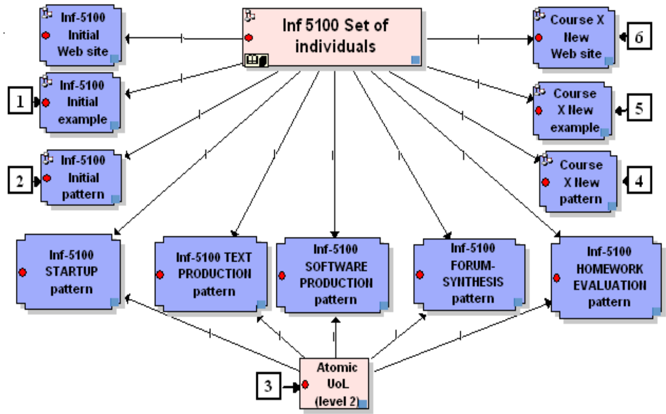

Fig. 5. A set on LDs in a Learning Design repository.

The interesting thing in this process is the evolution of the generic skill's references for the various LDs. Looking at the 5 level-2 patterns at the bottom of figure 5, we have the first one aiming at a simple information RECEIVING skill. The next two are at the REPRODUCTION level in the taxonomy. The fourth one embodies a synthesis PRODUCTION skills, while the last one involves META-COGNITION skills. We observe that the initial IA course and the resulting political science courses both involve a progression of generic skill levels through the five level 2 modules. This seems to be a sound cognitive progression strategy.

B. RDFS Vocabulary for LD referencing in ISO-MLR

While the above repository had many interesting applications like this one, this project revealed many limitations of the LOM specification when it comes to referencing LD objects.

First the LOM classification for the types of learning resources mix all kinds of things such as exams, questionnaires, reference documents, tutorials and learning activities. This last concept is confused with the notion of instructional scenario or learning design. Second, the LOM section 7 provides 6 kinds of relationships between resources in general. Some are useful for LDs (such as "has part"), others are two general (such as "is baiss for" or "requires"), while others are not really useful (such as "is based on"). We need more precise relationships based on the very structure of a learning design. Third, and more important, the LOM section 9, while providing the use of cutom-made classification had to be extended to include various taxonomies for competency, pedagogical strategy, delivery modes, évaluation modes, reusability criterias, among others. These taxonomies are not related. They do not form a LD ontology that could provide more expressivity and retreival power.

We need a more flexible aproach based on the new developpements that are occuring in the Semantic Web [1,6], more precisely on the Web of Linked Data [1,8]. As proposed by the W3C, the basic structure of the Web of linked data is the RDF, the Resource description framework.

This basic RDF framework has been adopted by the International Standards Organization (ISO) and the International Electro technical Commission for their new standard ISO/IEC 19788 Metadata for Learning Resources, in short ISO-MLR [11]. The new standard is intended to provide optimal compatibility with both DC (Dublin Core) and the IEEE-LOM. It supports multilingual and cultural adaptability requirements from a global perspective.

We have begun the development of a LD (or scenario) referencing vocabulary aiming to extend ISO-MLR part 5, the "Pedagogical Elements" part of the standard. The vocabulary is described as a RDF schema (RDFS) vocabulary that provides the required scope and flexibility for a LD lightweight ontology. The SCEN vocabulary has three main parts: the LD concept, the LD taxonomies and the LD context.

The LD concept is shown on figure 6. A LD scenario is composed of the actors, the activities and the resources that compose the scenario. The structure of a LD scenario is defined by three RDF properties (not shown on the figure: first its URL, providing its location on the Web; second, its general structure, a choice between values such as free list of activities, sequence, hierarchy or network; and third, the format of its description that can be a narrative text, a template, a graph or a standard SCORM or IMS-LD manifest.

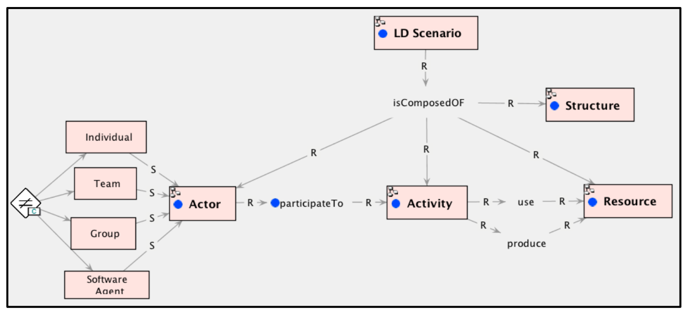

Fig. 6. The learning design scenario components

The LD taxonomy part includes the cognitive strategy presented on figure 7. It includes the generic skill in the LD scenario, the knowledge type and the meta-domain.

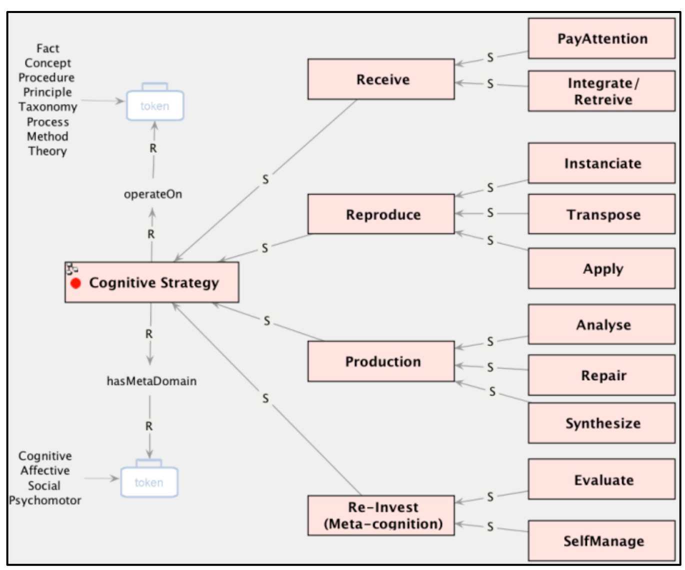

Fig. 7. A taxonomy and two properties for a LD's cognitive strategy.

Other taxonomies in the RDFS model are provided for the pedagogical strategy in a LD scenario, its collaborative mode, its delivery mode, its evaluation model and its reusability on the technical, content, context and accessibility dimensions. Contrary to the previous LOM model, these taxonomies are linked together to provide more search capability.

Finally, the LD context includes the intended audience, the scope (program, course or module) and the possible relationships to other scenarios, as shown on figure 8.

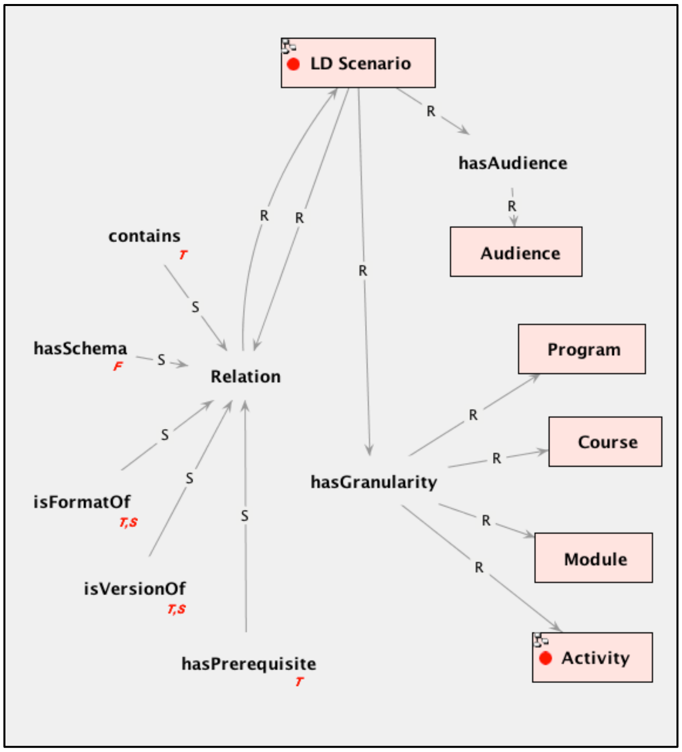

Fig. 8. LD context components: audience, scope and relationships

We retain 5 types of relationships between LD scenarios:

- *contains* (ex: the relation between course and module scenarios), which is transitive;
- *hasSchema* (ex: the relation between course and course pattern), which is functional;
- *isFormatOf* (ex: the relation between a LD graph and its narrative description), which is transitive and symmetric;
- *isVersionOf* (the relation between successive representations), which is transitive and symmetric;
- *hasPrerequisite* or pedagogical ordering, for example based on generic skills or knowledge content, which is transitive;

All the LD classes, the object properties and the data properties in theses models need to be precisely described. In order to improve search operations on the Web of linked data it is good practice to link these vocabulary elements to already described vocabularies such as ISO-MLR, DC or FOAF. Table II provides such associations for part of the class elements on figure 6, 7 and 8. Other similar tables have been built to provide similar information for all scen classes and properties.

TABLE II. A SAMPLE OF VOCABULARY ELEMENT DESCRIPTIONS

Class Name	Sub-class Of	Definition
scen:Scenario	ISO_IEC_19788-1:2010::RC0002 dcmi :Collection dct : MethodOfInstruction foaf :Document	A scenario in a learning resource as defined in iso-mlr-1. It is also a Dublin Core collection and a method of instruction. Finally, it is a FOAF document
scen:Actor	ISO_IEC_19788-1:2010::RC0002 dct:Agent	An actor is also a learning resource in iso-mlr-1 It is also a Dublin Core agent, which is a person, an organization, or a software agent.
scen:Activity	dcmi:event	An activity is a Dublin Core event, that is a non-persistent event situated in time for duration.
scen:Resource	ISO_IEC_19788-1:2010::RC0002 foaf :document	A resource in a scenario is a iso-mlr-1 learning resources, as well as foaf:document
scen:Audience	ISO_IEC_19788-5:2010::RC0002 dcmi : Groupe	The audience of a scenario is a sub-class of the class mlr5:audience and also a group according to Dublin Core.
scen:Learning Structure	ISO_IEC_19788-5:2010::RC0003	A learning structure is a learning program, a course or a learning unit that refines the class mlr5 :curriculum(fr)
scen:Cognitive Strategy	rdf:class	This is a generic auxiliary class that contains the values for generic skill, knowledge type and meta-domain.

V. Conclusion

Reusable learning designs and LD repositories is large-scale initiative based on the important task of structuring important parts of meta-knowledge, the knowledge that applies to knowledge, more precisely the properties of generic skills that apply to various knowledge domains.

The graphic language and the few examples presented here have aimed at demonstrating some of the complex interrelations between generic skill's processes and specific domain knowledge. These associations seem a promising approach because they root learning designs in the rich relationship between specific domain knowledge and meta-knowledge. The most stimulating aspect of a generic skills taxonomy built at the meta-knowledge level is the opportunity it provides to create an expandable and adaptable set of visual models to help solve that huge puzzle of learning environment engineering.

The implementation of these ideas into the Web of linked data still presents important challenges, especially on the usability dimension. Some use cases are promising but they will have to be thoroughly tested before we can claim sound and practical results have been achieved.

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