Adaptivity for Knowledge Content in the Semantic Web

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ABSTRACT

The focus of this report is the adaptivity issue for Learning Objects owned by Learning (Web) Services. We address this issue based on the Concept, Resource, Order, Product (CROP) Reference Architecture that we briefly review here. Based on the essentially recursive notion of a learning object in our CROP architecture, we propose that adaptivity of learning objects is best viewed as a property of the network of learning services and the learning objects they own, i.e. as an emergent property of learning service communication and collaboration. For such a communication and collaboration to be successful with respect to an adaptive response goal, we propose that (besides adopting a standard reference architecture for learning objects) a global model of learning styles needs to be agreed upon. We contribute in this direction by presenting a basis for a global model of learning styles, by elaborating a systematic classification of the learning styles dimensions proposed in various models, uncovering relationships of concept identity or subsumption and distinguishing between base and definable concepts.

Keywords: Adaptive Learning Objects, Learning (Semantic Web) Services, Learning Styles.

1. INTRODUCTION

In [10] we proposed a minimal reference architecture for Learning Objects, the CROP (Concept, Resource, Order, Product) Architecture. CROP learning objects are simple and lack any intelligence or explicit adaptation capability. In this report, we turn to investigating adaptability issues for learning objects, based on the CROP Reference Architecture. We emphasize, however, that in our view adaptability is not a requirement to be met by an individual learning object and this is not simply a reflection of the difficulties arising from the number of combinatorial variations of style produced by any learning styles model with a large number of learning styles dimensions. Adaptability is possible, we argue, when considering learning objects not in isolation, but as part of a network of learning objects, offered for use to their clients by collaborating Learning (Web) Services, at least if a standard reference architecture, such as our own CROP Reference Architecture [10], is adopted.

Engineering adaptive educational environments requires an understanding of and agreement on the features of the learner the system is to adapt to, as well as on the rationale, nature and purpose of the adaptation itself. Turning to research relating to Learning Styles seems to be the natural way to begin to address the first issue. However, even though research on Learning Styles has proliferated over the last twenty years, recent reviews [4] come to the conclusion that there is in general severe lack of independent corroborating evidence and many of the claims advanced by the proponents of learning styles theories remain unsupported. In this regard, we find ourselves in agreement with [15], as far as the need for a unified learning styles model is concerned, and the present report contributes in this direction.

We propose that to the extent that for the majority of the theories a style is merely a combinatorial construct formed from a number of bipolar dimensions (composed of two opposing learning type designators), the base for a global, unified model can be taken to be a systematic and rigorous classification (taxonomy) of learning type designators. Producing a rigorous taxonomy presents itself both as a disambiguation task and as a correlation of concepts originating in disparate theories, often with divergent ideological, or philosophical presuppositions, yet presumably purporting to measure similar, or complementary, characteristics in learning attitudes. For example, Figure 1 below shows the learning style designator's of Kolb's theory

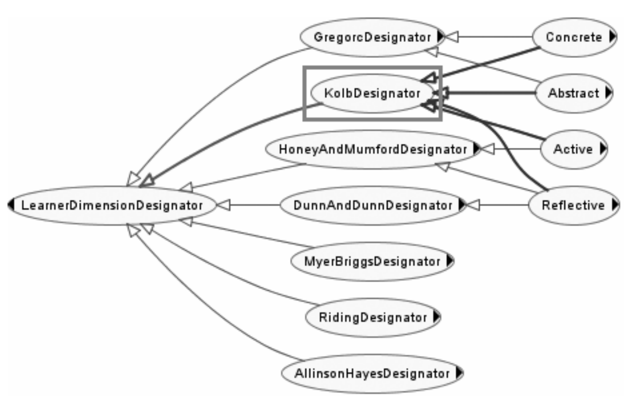

Figure 1: Style designator overlap across theories

(abstract-concrete and active-reflective), determining two dimensions. As shown in Figure 1, some of the designators are used by other models as well, paired with the same (as is the case with Gregorc's model [8], [9]) or even different designators (as is the case with the Dunn and Dunn model [6] and the designator “reflective”), to form (by combination) different learning styles. This evidently calls for a clarification of how such models relate to each other.

2. LEARNING STYLES

2.1 A Brief Commentary on the State of the Art

To begin with, there is no generally agreed definition of “learning style”. The literature on learning styles is indeed prolific (more than 70 models are mentioned in [4]), yet it only consists in a (large) number of distinct theories, each advancing claims that, by general consensus, seem not to be sufficiently supported by appropriate evidence, with no mapping between different theories to facilitate comparative understanding and no generally agreed taxonomic approach that would collect similar -- in a sense in need of definition! -- theories into a few distinct clusters. Two of the main taxonomic approaches are Curry's [5] (followed in Swanson's [21] review on learning styles theories) and Coffield at al [4].

Curry distinguishes between three successive layers, with *cognitive style* at the (more stable) core, next *information processing style* and, finally, the more flexible and changeable *instructional preferences* layer.

Coffield at al [4] base their classification on a continuous scale of stability vs changeability claims advanced by the theories under review.

In this report, we proceed by uncovering connections across theories, based on the definitions and descriptive analyses of style offered by the proponents of various models, in the sense we explain below. First, we briefly pause to mention a proposal for a unifying learning styles model.

2.2 Merging Learning Styles Models

In [15], a proposal has been advanced for a unified learning styles model, with the suggestion that “instead of arguing over the best learning style, it is undoubtedly better to take the best of each model and use a complex of features, each with its own importance and influence”. The authors propose to consider “learning preferences related to:

- environment (noise, light, temperature, comfort)
- physical dimensions (time of the day, mobility)
- perception modality: visual (text/images), auditory, kinesthetic
- field dependence/field independence
- processing information (abstract concepts and generalizations vs. concrete, practical examples; serial vs. holistic; active experimentation vs. reflective observation)
- reasoning (deductive vs. inductive)
- organizing information (synthesis vs. analysis)
- motivation (intrinsic vs. extrinsic; deep vs. surface vs. strategic vs. resistant approach)
- persistence (high vs. low)
- pacing (concentrate on one task at a time vs. alternate tasks and subjects)
- social aspects (individual work vs. team work; introversion vs. extraversion; competitive vs. collaborative)
- study organization (formal vs. informal)
- coordinating instance: affectivity (intuition, feeling) vs. thinking (analysis, mental reasoning, focus on detail).”

However, though we find ourselves in agreement with the idea of a global learning styles model, the approach initiated in [15], restricted to selectively “gathering characteristics from various learning styles proposed in the literature”, needs further development and refinement and the present report contributes in this direction.

2.3 The Definitional Basis for Learning Styles: Extensional and Intentional Definitions

In most theories, learning styles result as combinatorial constructs, based on a number of linear, bipolar *base dimensions*, such as *concrete vs abstract* and *active vs reflective* in Kolb's model. In Kolb's model, taking all four combinations results in four types: concrete/active (*accommodating style*), concrete/reflective (*diverging style*), abstract/active (*converging style*) and abstract/reflective (*assimilating style*). Note also that each of the opposing terms in a dimension can be regarded, in itself, as a style descriptor.

In some theories, combinatorially resulting styles themselves can be arranged in bipolar dimensions, such as the *accommodating vs assimilating* and the *diverging vs converging* dimensions in Kolb's model.

Remark: Further combinatorial formations on the resulting combinations may become meaningful when considered as *ordered combinations*, indicating a move from style to style in the course of the learning process. For example, Kolb's experiential learning model is based on the consideration of the ordered combinations

diverging → *assimilating*
converging ← *assimilating*
converging → *accomodating*
diverging ← *accomodating*

resulting in the learning cycle

$$\begin{array}{ccc} \textit{diverging} & \rightarrow & \textit{assimilating} \\ \uparrow & & \downarrow \\ \textit{accomodating} & \leftarrow & \textit{converging} \end{array}$$

It is not clear whether Kolb intends to propose a *descriptive*, or a *prescriptive* (*normative*) view on learning style.

Some proposed models, such as the Honey and Mumford model (reviewed in [4] and critically discussed in [20]) do not make explicit the base dimensions on which proposed styles are combinatorially defined, proceeding directly to consider ordered combinations of upper layer styles.

Thus far we have alluded to models that consider only psychological/cognitive preferences as determining a learning style. Other models expand on different aspects, on top of the psychological/cognitive aspect. For example, the Dunn and Dunn model [6] (reviewed in [4]) lists five different aspects of style determination: (1) Psychological/ cognitive (based on the *global vs analytic* and *impulsive vs reflective* dimensions), (2) Emotional (measured on a continuous scale from ‘very low’ to ‘very high’ on each of the dimensions *motivation, degree of responsibility, persistence, need for structure*), (3) Sociological (measured similarly on a continuous scale for preference or inclination on each of the dimensions *learning groups, support from authority figures, working alone or with peers, motivation from parent/teacher*), (4) Environmental (similarly, on the dimensions *sound, temperature, light, seating and room layout*) and (5) Physical (similarly again, on each of the dimensions *modality preference (visual, auditory, kinaesthetic, tactile), intake (food or drink), time of day, mobility*).

Researchers in the field often propose models that overlap with existing models, adopting a different terminology for their own proposal. For example, one finds a holist-serialist dimension in Pask [14], but a (hardly distinguishable) global-sequential dimension in Felder and Soloman [7], partly overlapping (at the first pole) with a global-analytic dimension in Dunn and Dunn [6], in its turn hardly distinguishable from the holist-analytic dimension in Riding [17] and partly overlapping (on the other pole) with the intuitive-analytic dimension in Allinson and Hayes [1].

Typically, learning styles theories restrict the number of dimensions to very few, ranging from just one, as in the Allinson and Hayes model [1], to perhaps four (or more) as in the case of the Myers and Briggs personality types theory [13], resulting in sixteen different types.

The number of base dimensions proposed in a model constitutes the foundation for the *extensional* definition of styles. Learning styles theorists, however, will also typically propose an *intensional* definition, characterizing a style by a number of distinguishing traits. For example, in the Myers-Briggs model, the type INFP (Introverted-Intuitive-Feeling-Perceiving) is intensionally characterized by a number of positive (artistic, reflective, sensitive) and negative (careless, lazy) traits (from [4], p. 47). For another example, Gregorc's *concrete/random* style is intensionally characterized (in [9]) by traits such as *intuitive, impulsive* etc.

The main observation in this regard is that even though the content of the intensional definition of style may often present itself as speculative and conjectural, it nevertheless provides the means to establish connections amongst style descriptors originating in distinct theories.

3. TOWARDS A GLOBAL LEARNING STYLES MODEL

We view a global learning styles model as the result of a systematic and rigorous classification of the concepts involved in determining the poles of learning types dimensions, originating in distinct theories. We propose that this can be done by taking into consideration the connections established between distinct theories through the intensional characterization of style offered by the theory proponents. This approach, and the results we present by following it, remains subjected to the limitations of conjectural claim that are inherent in the learning styles theories themselves and an empirical validation of the connections indirectly stated by the proponents of the learning styles models and which we bring to the forefront in this report is of course desirable.

With textual analysis and based on the intensional characterization of learning styles provided by the proponents of a small number of models, as well as on explicative commentaries by various authors, the correlations amongst style descriptors across distinct models we have systematically sought to unveil are depicted in Figure 2, restricted (as an example and for proof of concept purposes) to a consideration of the dimensions listed below:

- abstract-concrete: Gregorc, Kolb
- introvert-extrovert, Myers-Briggs
- random-sequential: Gregorc
- active-reflective: Kolb, Honey and Mumford
- impulsive-reflective: Dunn and Dunn
- global-analytic: Dunn and Dunn
- holist-analytic: Riding
- holist-serialist: Pask
- innovator-reasoner: Jackson
- implementer-analytic: Jackson
- pragmatist-theorist: Honey and Mumford
- intuitive-analytic: Allinson and Hayes
- intuitive-sensing: Myers-Briggs
- field dependent - field independent: Witkins

In Figure 2, dimensions are enclosed in rectangles, double-headed arrows connect the opposing concepts of a dimension and single-headed arrows indicate a relationship of concept subsumption.

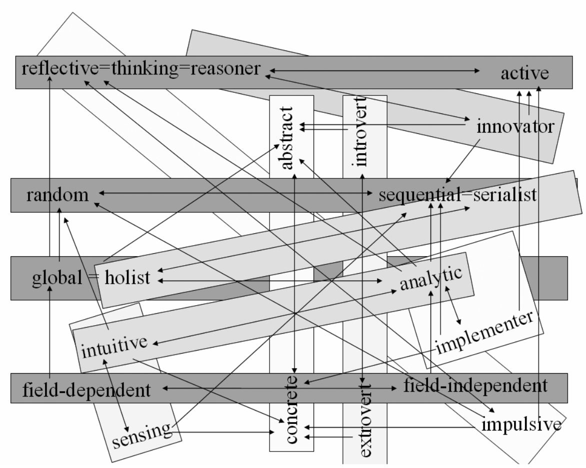

Figure 2: Correlation of dimensions across distinct learning styles models

Figure 3 depicts the classification (coded in Protégé) of the style dimension designators appearing in Figure 2. To the best of our knowledge, this is the first attempt to establish a mapping amongst the style constructs of distinct theories. We emphasize that this mapping is not imposed on arbitrary grounds, but that it results by systematically examining implicitly stated connections that appear within the models considered, when styles are described and explicated intensionally.

4. LEARNING STYLES ONTOLOGY AND ADAPTIVITY FOR LEARNING OBJECTS

The objective of systematically developing a global learning styles ontology by expanding on the basis for such an ontology that we presented in this report is not merely (or even primarily) to bring some order to the generally regarded as “jungle” of learning styles literature. Rather, we propose, it is a vehicle for resolving in a novel way the adaptivity problem for Learning Objects. We explain in more detail in the sequel, after briefly reviewing our notion of (distributed) Learning Objects (as defined in the CROP Reference Architecture [10]) and of

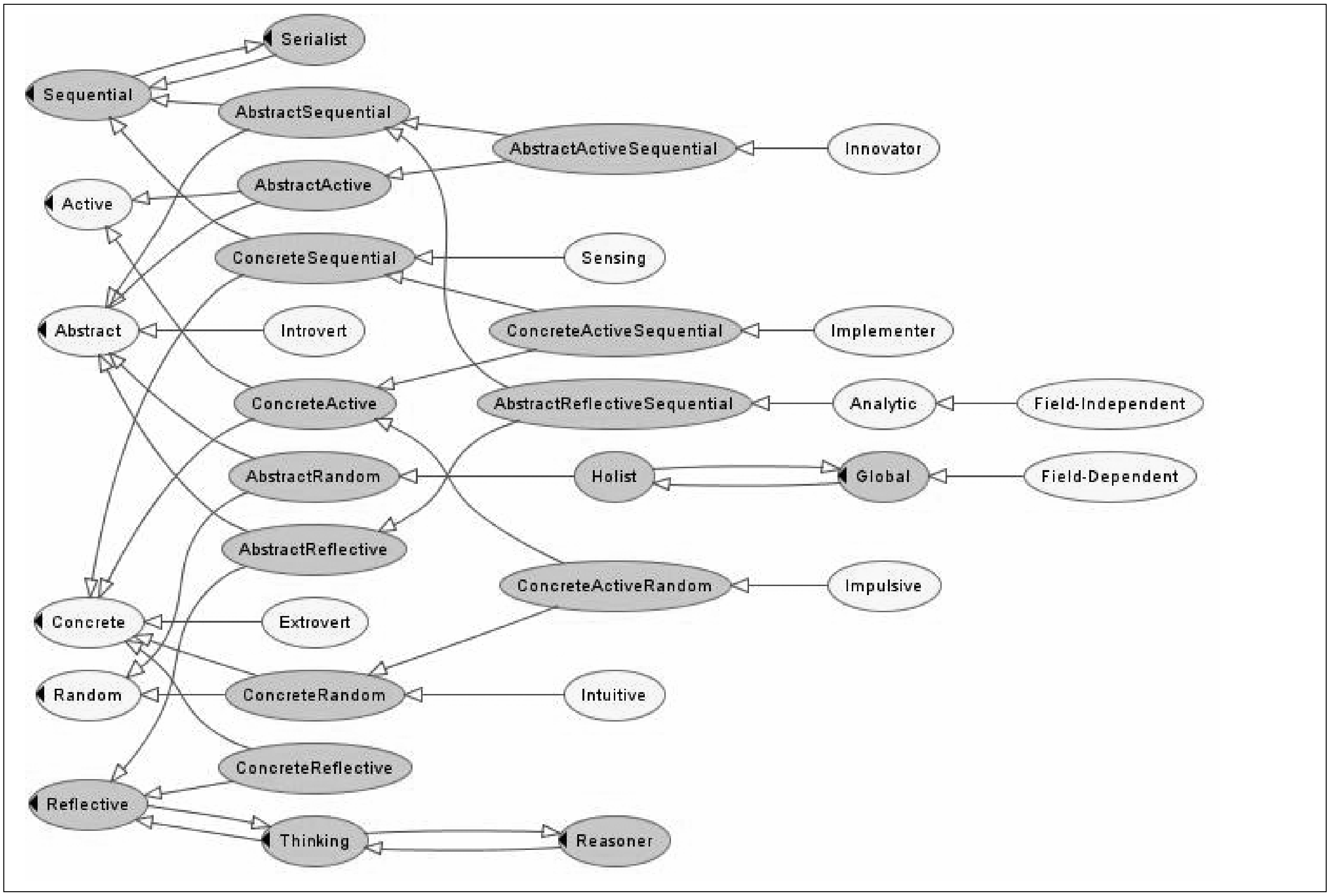

Figure 3: The Taxonomy of the Learning Style Dimension Designators appearing in Figure 2

Learning Services that own them.

4.1 A Brief Review of the CROP Reference Architecture for Learning Objects

With the development of the web and the intense research for a *semantic* web, the need arises for standardized and rigorous semantic specification both of Services on the semantic web and of the objects and processes that these Services offer to a potential user (client). Our own focus is with Learning Services, i.e. Web Services whose purpose is to offer educational services to clients. Such services are the owners of Learning Objects, which they deliver for use to their clients.

In [10] we presented in detail a minimal Learning Object Reference Architecture, using ontological engineering techniques for the specification of an architecture based on the notions of *Concept, Resource, Order* and *Product* (*CROP-Architecture*). The terms KConcept, KResource, KOrder and KProduct are the class names in the CROP ontology that designate, respectively, these notions. In the sequel we briefly present the main concepts and idea of the CROP Architecture.

The aim of the CROP Reference Architecture is to put forward a standard of internal structure that a learning object is to abide by, without making any commitment to particular educational/teaching theories, instructional strategies, styles or preferences, being flexible enough to accommodate different stances on such issues, while providing a solid foundation and laying out the way for the deployment of relevant technology to assist the development of Learning Objects.

Note that the terms *Learning Object* and *Knowledge Product* (KProduct) have exactly the same meaning in the CROP Architecture. In fact, we use the term KProduct only to refer to a learning object that is a sub-object of a Learning Object under discussion.

The two main entities in the Learning Object Reference Architecture, we propose, are those of a KConcept and a KObject. A KObject is of one of two main types, KResource and KProduct.

1) KConcept: The KConcept class instances are concept items, be that the concept of "vector space", or "chess-board configurations in which one of the opponents is check-mated within at most twenty-five moves", or the concept of "english language sentence", etc. In short, a KConcept instance is anything that may be set as a learning/teaching objective.

A Learning Object, in our view, is accompanied by an ontology, a structured class of concepts (and restrictions) that constitute the subject of learning. Concepts and binary relations on concepts are specified in OWL-DL, hence essentially using the syntax of Description Logic. As OWL-DL provides complex concept constructors, including union, a Learning Objects's ontology can always be equipped with a top concept (even if this is an aggregate concept, a union), which is precisely its target concept.

The notion of concept, as we propose in [10], is a recursive notion, with concepts possibly having other concepts as parts. This part-of relation between concepts designates a logical precedence relation, or a relation of dependence between concepts. For example, the concept of "angular velocity in circular motion" has each of the concepts "angular velocity" and "circular motion" as parts. A GroundConcept can be then rigorously defined as a concept that has no parts (no prerequisites). A concept may be considered ground in a Learning Object, but not necessarily so in other Learning Objects. Thus, the ground concepts of a Learning Object are precisely those either assumed to be known to the consumer of the Learning Object, or those that the Learning Object holds to be indecomposable into simpler concepts.

The set of concept items (KConcept instances) of a Learning Object, together with the part-of (prerequisite) relation constitute the backbone of the ConceptGraph of the Learning Object.

2) KResource: KResources are *atomic* KObjects. A KResource item is a learning resource, associated to a file that contains the actual learning material. Every KResource is declared to have a unique target concept (which may nevertheless be an "aggregate" concept, i.e. a union of perhaps interrelated concepts), through the hasTargetConcept relation. Further, a KResource item has its own LOM, like Learning Objects, which captures all metadata information pertaining to the resource (such as technical requirements, in the Technical element of the LOM, versioning information, in the LifeCycle element, or authorship information, in the MetaMetaData element).

3) KProduct: The single main component type of a Learning Object (other than its domain ontology) is the KProduct type. Recall that the terms *Learning Object* and *Knowledge Product* (KProduct) have exactly the same meaning in the CROP Architecture. And that we use the term KProduct only to refer to a learning object that is a sub-object of the Learning Object under discussion.

A KProduct is an executable item. The KProduct has two components (from the KProductComponent class), the ConceptGraph and the execution model (ExecutionModel class). The execution model prescribes how the nodes of the concept graph are to be executed, in the course of an interaction with a user.

The ConceptGraph is a directed, rooted graph, where the root (the target concept) is the top node (the source) of the graph. A ConceptGraph is the essential component of a KProduct and it has, in its turn, two types of components, TeachingAct components (graph nodes) and TeachingStep components (directed graph edges). A ConceptGraph node (a TeachingAct) is a self-contained teaching act and it will be executed provided all of its predecessor nodes in the ConceptGraph have been executed (unless the user wishes to override the default execution model of the KProduct).

As already pointed out, the ConceptGraph of the KProduct is derived from its concept ontology. Each node is therefore associated to a KConcept (the target concept of the node/ TeachingAct) and ConceptGraph edges (TeachingStep items) are determined by the isPrerequisiteOf relation on concepts.

Further, each ConceptGraph node is associated to a *node type*, a KObjectList, whose members are either KProduct or KResource items. The KObjectList (a subclass of rdfs:List) encapsulates the support or assessment material needed for performing the TeachingAct (executing the ConceptGraph node and teaching --or testing on-- the target concept of the node).

As we discuss in Section 4.4, adaptation of a Learning Object takes places precisely by modifications affected to the node types of its concept graph.

4) KOrder: The KOrder is the manager of the interaction between the KProduct and the Learner. It processes any available information on the Learner knowledge level, learning style and preferences, and constructs an instance of the StudentModel. Further, it monitors the KProduct - Learner interaction, it modifies appropriately the StudentModel and it provides the necessary information for adapting execution of the KProduct to the user profile.

4.2 Learning Services and Distributed Learning Objects

A Learning Object may consist of a single KResource having a degenerate one-node KRC; or it may consist of (several KResource instances and) other Learning Objects (KProduct instances). Our proposed notion of a Learning Object is essentially recursive, each component Learning Object of some Learning Object having the exact same architecture (the CROP Architecture, according to our proposal in [10]). It is then natural to admit of *distributed Learning Objects*, i.e. Learning Objects whose component Learning Objects may reside at different physical locations. It is, in this view, entirely possible to have a Learning Service that, in delivering a service to a client, needs to communicate with other Learning Services and secure usage of a Learning Object that is listed as a component of the Learning Object ordered in the first place by its client. The same of course applies to KResource items. An immediate advantage of this is the possibility of reuse of Learning Objects, by several Learning Services, as components of distinct, larger Learning Objects.

A truly necessary condition for an Open Learning Environment as the one outlined above is for Learning Objects to have essentially the same abstract structure, the same architecture, so that information about the objects (learning object metadata) can be uniformly extracted and building new Learning Objects from existing components can be made possible.

4.3 Learning Object Metadata

Discovery of Learning Objects is facilitated by a metadata element. In [10] we have adopted the LOM (Learning Object Metadata) structure, which we have re-engineered as a Learning Object Metadata Ontology (see [11]). Restrictions and appropriate inheritance axioms are included in the development of the LOM ontology, so as to capture the intent of the LOM designers, as depicted in verbal presentations of LOM in [12].

Each Learning Object possesses its own metadata LOM Element, which captures nearly all information *about* the

Learning Object that is necessary for the discovery of the Learning Object by potential users. What is missing from a LOM element is, first, some way to refer to what is being learnt by a potential user of the Learning Object, which, in our view, is the *target concept* (and the associated *ontology*) of the Learning Object; and, second, some indication as to the *type of learner* the Learning Object is best suited to. It is in this context, in the view proposed here, that the significance of having a global learning styles ontology becomes evident, providing an underlying concept structure for uniform annotation of Learning Objects.

4.4 Design Time and Mutated Learning Objects

Shifting from a practice of Learning Objects implemented as standalone applications (various Tutoring Systems, intelligent or otherwise) to a view of Learning Objects as the objects owned and offered for use by Learning Services deployed in the semantic web requires a re-examination of the issue of adaptation of a Learning Object to the needs of a particular user. With standalone applications there seemed to be no other way to address this issue, except by specifically coding adaptation strategies to anticipated user differences. While this option remains open in a web setting, adaptation can now also take place by modifications affected on the fly to the KObjectLists, i.e. the node types of the KRC nodes (the TeachingActs), by adding or removing support or assessment KObjects (KResources or KProducts), as an adaptive response to diagnosed user needs, resulting in a mutated Learning Object. Further, such additions need not be the result of an adaptive procedure, internal to the Learning Object, implementing some adaptation strategy, that generates appropriate knowledge objects, but rather the result of searching, finding and binding with a Learning Object available through some other Learning Service.

4.5 Adaptive Learning Services and Objects

According to the view proposed in this report, adaptivity is to be regarded as an emergent property of Learning Service communication, triggered by the diagnosed needs of a user of some Learning Object owned by the Learning Service. The emphasis, we propose, is to be placed on implementing diagnostic strategies, based on student-tutor interaction and resulting in updating the classification of the student, with respect to a Learning Styles Upper Ontology. A potential lack of KProducts of the suitable Learning Style to support a TeachingAct will then trigger a cfp issued by the owning Learning Service and whose message-content is a metadata description of the required Learning Object.

5. CONCLUSIONS

We have argued in this report that in order to support dynamic adaptation of Learning Objects to a diagnosed learner style, an emphasis needs to be placed on designing and implementing suitable diagnostic strategies, based on continuous student-tutor interaction; further, as the diagnosis result is (an update of) the student learning style classification, searching for a suitable Learning Object can be facilitated by including in its metadata object a learning style tag (the style that this learning object is considered to be best fit to); in addition, we have proposed that having an underlying ontology (taxonomy) of learning styles indicators is necessary for that purpose and we have put forth in the present report a basis for developing an upper ontology of learning styles dimension designators. Such designators, in a fully developed upper ontology, may span across different learning styles models, but they are related within the same ontology, where relations of subsumption and a distinction of base and definable style designator concepts is implemented, in the sense proposed in this report for the base ontology we presented. Such relations can be uncovered (and then captured in the ontology) by systematic textual analysis based on sources presenting (or commenting on) different learning styles models, as we have done here, but only for a fragment of the learning styles models literature.

Further, we have proposed in this report that adaptation is not a requirement to be met by a Learning Object per se (though implementing suitable adaptation strategies is of course consistent with our view), but rather an emergent property of Learning Service communication, triggered by the diagnosed needs for stylewise specialized learning objects (knowledge products), to be (dynamically) incorporated in the support, or assessment, KObjectList of a TeachingAct, in the course of executing the KRC of the Learning Object currently offered for use by a Learning Service to a student.

Finally, we argued both in this report and in our [10], that in order to support such Learning Object exchange between Learning Services, as a dynamic response to diagnosed student needs, it is recommended that Learning Objects be designed in accordance to some architectural principles that address issues of structuring at a sufficiently abstract level, without prescriptively imposing chosen instructional strategies at all. We have proposed, in this regard, that a reference architecture for learning objects should be put in place and we have proceeded to advance a concrete proposal with the CROP reference architecture, briefly reviewed here and detailed in our [10].

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