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On the way to learning style models integration: a Learner's Characteristics Ontology

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ABSTRACT

On the way to increasing customization in e-learning systems, the learner model is the main source of variability. Such a model includes a number of psychological characteristics and study preferences that describe the learner's personality traits related to learning. During the last decades, the design methods and tools for e-learning have been designed assuming specific learner models. Therefore, in the search for a learning environment suitable for as many learner models as possible, we need tools to explore -and exploit- such models. In general, the learner's characteristics can be linked to the so-called *learner's learning style* (which is a part of the learner model) to provide the instructor with extensive knowledge about the learner's characterization in perceiving and processing information. Numerous learning styles have been proposed in the last decades, in some cases with overlapping characteristics with the same or different names. Thus, the heterogeneity of the learning style space makes it difficult to handle customization effectively. In this paper, we introduce a *Learner's Characteristics Ontology* based on creating interconnections between the different learning style model dimensions and learning styles with the relevant learner's characteristics, that: (1) helps instructors to improve and personalize the learning content; (2) can recommend learning materials to learners according to their learning characteristics and preferences; (3) can provide both instructors and learners with extensive knowledge about how they can improve their teaching and learning abilities; and (4) can improve communications and interaction between humans and computers by specifying the semantics of the learning style models' characteristics.

1. Introduction

The adoption of the Web as "the" platform for the deployment of e-learning environments has paved the way for the long sought-after customization in learning content management. Due its unique properties, the *learner model* is considered a pivotal issue to enforce customization/personalization in e-learning environments. It contains an important information about learner's personal data, cognitive traits, knowledge level, and learning styles and preferences, which can be used to adapt the e-learning environments to learners' needs. Specifically, the possibility of creating learner-based content, which varies in terms of the learners' different characteristics, is still being pursued by learning environment designers. These characteristics have been formalized through the concept of *learning style*, which is part of the learner model and, surprisingly, is not easy to define. Several studies on learning styles defined them as the individuals' approaches to learning based on their own preferences (Felder & Silverman, 1988; Honey & Mumford, 2000; Kolb & Kolb, 2005; Ramayah, Sivanandan, Nasrijal, Letchumanan, Leong, 2009). For us, a learning style will represent a set of *characteristics*, mostly related to personality and attitude, that a person shows when participating as a student in a learning process. In most cases, the characteristics are grouped into *dimensions* that are in turn grouped into what is called a *Learning Style Model*.

Since the early works in the 1970s, when the term "learning style model" was coined, the learning community has produced successive refinements that have resulted in a large list of proposals, many of them having some degree of overlapping concepts. As a matter of fact, in (Coffield, Moseley, Hall, & Ecclestone, 2004) 53 different learning style models were classified into a hierarchal structure called *Families of Learning Styles*, and 13 learning style models were evaluated regarding the theory behind each model.

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0747-5632/

Such diversity makes the development of a general purpose, multimodel learning tool very difficult. As a consequence, researchers often tend to adopt one learning style model, leaving others uncovered. Kurilovas and Juskeviciene created a Web 2.0 tool ontology to interconnect learning activities with appropriate Web 2.0 tools. The learning activities were extracted from the VARK (Visual-Verbal-Read/write-Kinesthetic) learning style (Kurilovas & Juskeviciene, 2015). On the same line, Ouf and colleagues proposed a framework for e-learning ecosystems; they categorize learning activities according to the Felder-Silverman model only (Ouf, Abd Ellatif, Salama, & Helmy, 2016).

Several research works concluded that paying attention to learner's learning characteristics increase the effectiveness and efficiency of teaching and learning activities (Kurilovas & Juskeviciene, 2015; Santos & Boticario, 2015; Thalmann, 2014; Truong, 2016). Ocepek and colleagues combine different learning style models with preferred types of multimedia learning materials for the purpose of designing a learning system (Ocepek, Bosnić, NančovskaŠerbec, & Rugelj, 2013). Santos and Boticario developed a set of practical guidelines to produce personalized recommendations for online courses (Santos & Boticario, 2015). Fouad proposed an approach for Semantic and personalized search of learning contents based on learning style and learning objects metadata (Fouad, 2011). Yasir and Sharif (2011) introduced a new adaptation approach of matching learning contents with learning styles and their influence on learner's achievement.

The variation in learner's learning characteristics, which is a substantial part of the learner model, is an important concern for addressing several issues e-learning systems must address, such as supporting personalized/adaptive learning material design and development, defining criteria to be used by recommender systems to suggest materials according to some learning characteristics, assisting learners to semantically search for learning materials, and enabling knowledge reusability for both humans and systems. We want to develop a generic learning materials authoring tool. By generic we mean that, unlike existing tools -linked to one or more learning style models- our tool will be able to search and reuse learning content regardless of the learning style model it was created with. Such feature requires what we could call *semantic learning style models interoperability,* provided by a catalog of learning styles, their characteristics, and the relationships between them.

In this paper, we introduce the *Learner's Characteristics Ontology,* which provides the conceptual base of the semantic interoperability between learning style models. The ontology was built from the analysis of six learning style models that we considered relevant according to the criteria explained later in the paper. We describe the models in detail, and compare them to find overlapping concepts from which to construct inter-model mappings. We also describe the steps taken in the development of the ontology, and give clues about the role it will have in LOAT, the Learning Objects Authoring Tool currently under development.

The rest of the paper is organized as follows. In Section 2, we give an overview of the main concepts behind our work. Section 3 contains the description of the six learning style models chosen for our study, making emphasis in their similarities. Section 4 describes the development process of the *Learner's Characteristics Ontology* using On-To-Knowledge methodology. Section 4 introduces a discussion about the approach. Finally, our conclusions and remarks on future work conclude the paper.

2. Preliminaries

Customization/personalization models in the e-learning domain are built on top of a few concepts that we describe in this section. The goal is to create learning materials adapted to particular student characteristics, trying to optimize his/her abilities and then learn better and faster.

2.1. Learner model

A learner model, sometimes called student model (Riad, El-Minir, & El-Ghareeb, 2009) is the system's representation of a specific learner's characteristics that may be relevant for personalized interaction. The learner model is not intended to be a representation of the mental state of the learner; rather, it contains several learner's details such as personal information, cognitive traits, knowledge level, and learning styles and preferences (Murray & Pérez, 2015). Furthermore, in personalized e-learning systems, learner models catch and save data about learners' personal information, knowledge, preferences, needs, learning goal, and learning styles. These data are grouped in two sets, namely domain-specific information and domain-independent information. The first set includes information about the learner's knowledge (e.g. knowledge level, insight about knowledge, etc.), and the second one is in turn divided into two information subsets: the psychological model and the generic model of the learner. The former contains data related to learner emotional and behavioral aspects, whereas the latter includes information about learner interests, learning goals, motivations, experience, and preferences (Brusilovsky, 1994; Murray & Pérez, 2015).

There are several learner model standards published in the e-learning field. The IEEE[1] Public and Private Information standard, called PAPI Learner (IEEE, 2001) and the IMS[2] Learner Information Packaging standard (IMS, 2002) are among the most used nowadays.

2.2. Learning style & learning style model

The learner's learning style describes the learner preferred way in which he/she perceives, processes and retains information during a learning process. One of the most important elements of a learner model, the learning style is a component of the domain-independent information, and describes *"characteristic cognitive, effective, and psychosocial behaviors that serve as relatively stable indicators of how learners perceive, interact with, and respond to the learning environment"* (Curry, 1981). Kolb and Kolb gave their own view of learning style as *"the description of individual differences in learning based on the learner's preference for employing different phases of the learning cycle"* (Kolb & Kolb, 2006).

A learning style defines learner behavior in terms of a set of characteristics such as *Diverging* (the divergent learners are emotionally-oriented, and tends to be creatively) or *Converging* (the convergent learners have interest in application and applies logic and concept).

In general, learners show more than one learning style, corresponding to different characteristics that can be observed on them. Moreover, researchers found different patterns corresponding to the aggregation of specific learning styles in individuals. Those patterns were called learning style models. They are compositions of several aspects that describe the modes in which learners perceive and process information. Different learning style models employed different theories on defining and categorizing learning styles, as we show in Section 3.

[1] Institute of Electrical and Electronics Engineers - www.ieee.org.
[2] Instructional Management System project - www.imsglobal.org.

2.3. A conceptual framework for learning style models

To summarize the above definitions, as well as to make their interrelationships explicit, we have defined a metamodel that represents the domain of learning style models. This metamodel is the conceptual base for the construction of the Learner's Characteristics Ontology that we will use in the integration of the different learning style models. Fig. 1 shows the metamodel defined using the Unified Modeling Language class diagram notation. For us, a learning style model (represented by the *Learning_Style_Model* class) is composed of a number of dimensions (*Dimension* class) representing individual ways of dealing with information (e.g. *Perception*, *Ordering*, etc.). Subsequently, each dimension is made up as a discrete spectrum or two opposite poles (e.g. a *Perception* dimension can be defined by two poles: *Intuitive* and *Sensing*; similarly, an *Ordering* dimension can be defined by *Sequential* and *Randome* poles).

Each pole (*Pole* class) is described by several learner's characteristics (*Characteristic* class). We introduce this class to ease the management of the semantic searches of learning materials because a learner's characteristic represents a preference or feature of a pole. Finally, a learning style (*Learning_Style* class) is typically built from two or four poles. For instance, an *Assimilating* learning style is formulated by combining the *Abstract Conceptualization* and *Reflective Observation* poles. On the other hand, learning styles are also associated to characteristics to facilitate the semantic searches. The cardinalities of the relationships in the conceptual model come from the study of different learning styles, as we describe below.

3. A review of learning style models

In this section, we introduce the six learning style models that were included in our study. There were two criteria behind the selection of these models. Firstly, according to the classification model suggested by Curry in (Curry, 1983) known as the *Onion Model*. Curry introduced a model to organize types of learning style models based on a survey of 21 identified models. The model was initially structured into three strata, from inner to outer: Cognitive Personality, Information Processing, and Instructional Preferences. The Instructional Preferences stratum describes the preferred way the individual interacts with the learning environment. The *Felder-Silverman* model (see 3.2) is an instance of such stratum. The Information Processing stratum focuses on the individual's approach to process information. Two models representing this stratum are *Kolb* (see 3.1) and *Honey & Mumford* (see 3.6). Finally, Cognitive Personality stratum describes the learning behavior associated with the individual's personality style, not with the learning environment. *Riding* (see 3.3), *Myer-Briggs* (see 3.4), and *Gregorc* (see 3.5) models represent the inner stratum. The second criterion we used to select the learning style models was their extensive usage in scientific papers, as pointed out by (Özyurt & Özyurt, 2015). We describe the six learning style models selected in terms of the conceptual model shown in Fig. 1.

3.1. Kolb's Experiential Learning Theory

Following works of Dewey, Lewin and Piaget, the Experiential Learning Theory was developed by D. Kolb in 1970. Kolb believed that each person has his/her own characteristics or preferences that help him/her to learn better. To Kolb, knowledge came from the blending of *Perceiving* or *Grasping* and *Transforming Experience* (Kolb & Kolb, 2005). He defined a learning model composed of two orthogonal dimensions, one for *Grasping* and another for *Transforming*. The *Grasping* dimension poles are *Concrete Experience* (*CE*) and *Abstract Conceptualization* (*AC*). Similarly, the *Transforming* poles are *Reflective Observation* (*RO*) and *Active Experimentation* (*AE*). The characteristics associated to each dimension pole are listed in Appendix A1.

Kolb also defined four learning styles obtained from combining the *Grasping* and *Transforming* dimensions:

- *Diverging* (*CE-RO*). Diverger students favor collecting information extensively and tend to be imaginative thinkers.
- *Assimilating* (*AC-RO*). They have some abilities like collecting information, converting it into a global view and creating theoretical models.
- *Converging* (*AC-AE*). The converger students favor dealing with applications and problems and prefer to come to the decision after solving the problem.
- *Accommodating* (*CE-AE*). Learning through doing and feeling is a good way for accommodators. They are excellent in working with groups.

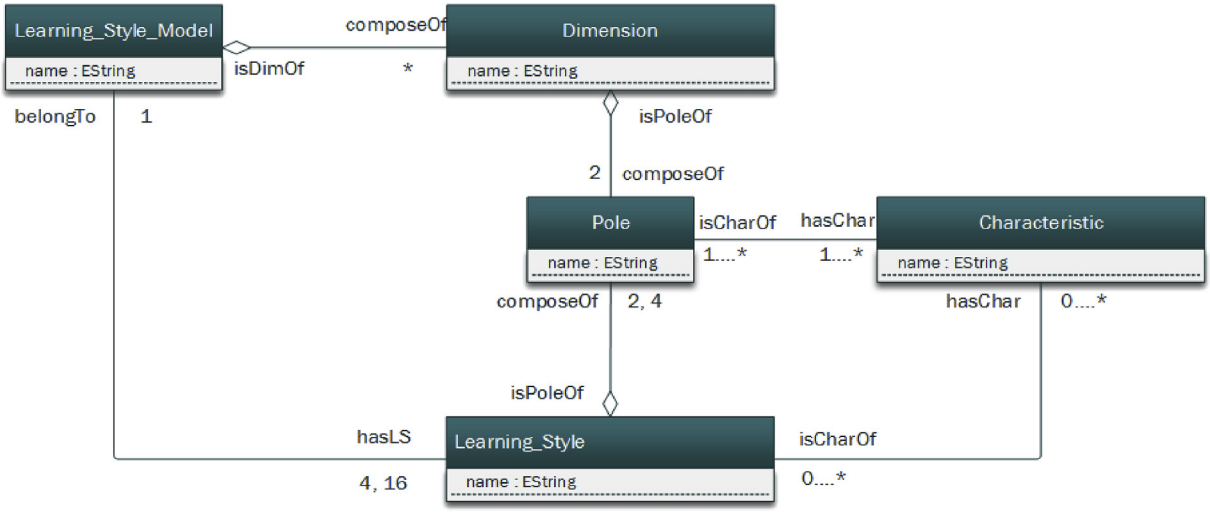

Fig. 1. Metamodel of the learning style models domain.

3.2. The Felder-Silverman model

The Felder-Silverman learning style model is composed of four dimensions (Felder & Silverman, 1988). The information *Perception* dimension (*Intuitive/Sensing* poles) derives from Jung's personality type theory (Jung, 1990). *Intuitive* persons tend to be creative, oriented toward principles and theories, and able to discover possibilities and relationships. In contrast, *Sensory* persons are patient with details and concerned with facts, procedures, and concrete contents. The information *Processing* dimension (*Active/Reflective* poles) is derived from *Kolb's Experiential Learning Theory*. *Active* persons acquire knowledge best by trying things out and working with others in groups. On the other hand, *Reflective* persons acquire knowledge best through thinking about things, then reflecting on the learning materials, and prefer to work alone or with one trusted person. The *Input* modality dimension (*Visual/Verbal* poles) was extracted from the cognitive theory. *Visual* persons like to receive information through pictures and diagrams, whereas *Verbal* persons like to retain information through written and spoken demonstrations. Finally, the *Understanding* dimension (*Sequential/Global* poles) was derived from Pask's learning style model. *Sequential* persons learn in small incremental steps, they are interested in details and prefer convergent thinking and analysis. *Global* persons understand in intuitive leaps and prefer to use Holistic Thinking. Felder and Silverman combined the four dimensions to define sixteen learning styles (*Intuitive-Active-Visual-Sequential, Intuitive-Active-Visual-Global*, etc.) (Felder & Silverman, 1988). The characteristics associated to each dimension pole are listed in Appendix A1.

3.3. The Riding cognitive style model

The Riding cognitive style model was designed as a two-dimensional model (Riding, 1991). On one hand, the *Wholist/Analytical* dimension is derived from the work of Witkin on field dependence and field independence (Witkin, Moore, Goodenough, & Cox, 1977) and describes the human way of organizing and processing information. *Wholist* people can perceive and process information globally, while *Analytical* people can organize and process information into a number of small parts. On the other hand, the *Verbal/Imagery* dimension, dependent on the work of Paivio's dual coding theory (Riding, 1991), describes the human mental representation of information. *Verbalizer students* prefer to represent information in words, whereas the *Imagers* prefer to represent information in a pictorial way. The characteristics associated to each dimension pole are listed in Appendix A1. Four learning styles are defined: *Wholist-Imagery*, *Wholist-Verbal*, *Analytical-Imagery* and *Analytical-Verbal* (Riding, 1991; Sadler-Smith & Riding, 1999).

3.4. The Myer-Briggs Type Indicator theory

The Myer-Briggs Type Indicator (MBTI) Theory was also developed on the basis of Jung's personality type theory (Jung, 1990). The MBTI theory has four dimensions that refer to the individual's personality types or preferences (Myers, McCaulley, Quenk, & Hammer, 1998). Each dimension has two uncorrelated poles, and each person tends to one pole in each dimension. So, sixteen unique personality types were generated. The four dimensions represent the core functions our personalities perform throughout our lives. The first dimension (*Sensing/Intuitive* poles) focused on how individuals perceived and gathered information. People with a *Sensing* personality function prefer to grasp and receive information literally. On the other hand, people with an *Intuitive* trait prefer to translate information into possibilities and associations; they prefer to comprehend the global view and ignore the details. The second dimension (*Thinking/Feeling* poles) describes how individuals come to decisions and make judgments. *Thinking* people prefer to use analytical logic, while, *Feeling* people prefer to come to a decision according to the personal impact. The third dimension (*Extravert/Introvert* poles) explains the individual's attitude to life. The last dimension (*Perceiving/Judging* poles) determines an individuals' attitude to the outside world. *Perceiving* people prefer to continue collecting information instead of coming to a decision. In contrast, the dominant trait for *Judging* people is their decision making (Cohen, 2008). The characteristics associated to each dimension pole are listed in Appendix A1.

3.5. Gregorc's mind styles model

Gregorc's model has two dimensions, namely *Perception* and *Ordering* (Gregorc, 1982). Firstly, the *Perception* dimension (*Concrete/Abstract poles*) describes two ways of grasping information. The *Concrete* pole explains how individuals prefer to grasp information through their five senses. *Concrete* persons deal with facts and reality and are interested in practical applications. On the other hand, the *Abstract* pole explains how individuals can visualize information that cannot be seen. *Abstract* persons tend to be intuitive and imaginative. Secondly, the *Ordering* dimension (*Sequential/Random* poles) describes the ways in which individuals arrange, order, and reference information. The *Sequential* pole represents how individuals deal with information in a linear and organized manner. *Sequential* persons prefer to plan things out step-by-step and are interested in details. The *Random* pole represents how individuals deal with information in chunks and skipping steps. *Random* persons are able to make connections between concepts and ideas. The characteristics associated to each dimension pole are listed in Appendix A1. Gregorc combined the two dimensions, leading to four learning styles: *Concrete-Random, Concrete-Sequential, Abstract-Random,* and *Abstract-Sequential* (Gregorc, 2006).

3.6. Honey and Mumford's model

Honey and Mumford defined four learning styles in their model, based on Kolb's learning cycle: The learning styles are *Activist*, *Reflector*, *Theorist*, and *Pragmatist* (Honey & Mumford, 1992). Each style has shared characteristics with a particular stage of Kolb's learning cycle. *Activists* learn best from short here-and-now tasks and they tend to be more eager about new ideas. They prefer to work with others and like to tackle problems by brainstorming. *Reflectors* prefer to learn by collecting and observing information then thinking about it. They like to generate analyses and reports. *Theorists* learn best through complex tasks and from theories and facts. They have the ability to visualize things by seeing the broad picture. And finally, *Pragmatists* learn best through hands-on experiences and practical applications. They enjoy solving problems and decision making (Honey & Mumford, 2000). The characteristics associated to each learning style are listed in Appendix A2.

3.7. Observations on learning style models

From our study on the six learning style models, we conclude that several common characteristics are shared among several dimensions in different models. Table 1 shows the linking between the dimensions of several learning style models described above and the common characteristics identified. Due to space limitations, only 25 of the shared characteristics are shown in Table 1. Here we list only three of the relationships found:

Table 1
Some Characteristics related to Dimensions of Learning Style Models[a].

Characteristics	Learning Style Models																											
	Kolb's Dimensions				Felder-Silverman's Dimensions								Riding's Dimensions				Myer-Briggs's Dimensions								Gregorc's Dimensions			
	Kolb-CE	Kolb-AC	Kolb-RO	Kolb-AE	FS-S	FS-IN	FS-A	FS-R	FS-Vi	FS-Vr	FS-Sq	FS-Gl	Rid-W	Rid-A	Rid-Vr	Rid-I	MB-S	MB-IN	MB-Th	MB-Fe	MB-Ext	MB-Intr	MB-Pr	MB-Jd	Gre-C	Gre-A	Gre-S	Gre-R
Literal Manner	✗				✗												✗								✗			
Tangible Facts	✗				✗												✗								✗			
Direct, Hands-on Experience	✗				✗												✗								✗			
Practical	✗				✗												✗								✗			
Concrete Thinking	✗				✗												✗								✗			
Look at The Big Picture		✗				✗												✗								✗		
Imagination		✗				✗												✗								✗		
Analyzing and Interpreting		✗				✗												✗								✗		
Theoretical Connections		✗				✗												✗								✗		
Logical Thinking		✗				✗												✗								✗		
Linear Thinking											✗			✗													✗	
Pictorial									✗							✗												
Written Demonstration										✗					✗													
Holistic Thinking												✗	✗															✗
Divergent Thinking												✗																✗
Content Map												✗	✗															✗
Working with others in Groups				✗			✗														✗							
Experimentalists				✗			✗																					
An Active, Doing Approach				✗			✗																					
Engage in Projects				✗			✗														✗							
Introspection			✗					✗																				
Theoreticians			✗					✗																				
Observation of Others			✗					✗																				
Use Analytical Logic																			✗									
Decisions based on Personally Held Values																				✗								

[a] Appendix B describes the acronyms of the column headers of the table.

- A learner related to Kolb's Concrete Experience (Kolb-CE), Felder-Silverman's Sensing (FS-S), MBTI's Sensing (MB-S), and Gregorc's Concrete (Gre-C) dimensions has several common characteristics like Literal Manner, Tangible Facts, Direct and Hands-on Experience, Practical, and Concrete Thinking, among others.
- The Felder-Silverman's Intuitive (FS-IN), Kolb's Abstract Conceptualization (Kolb-AC), MBTI's Intuitive (MB-IN), and Gregorc's Abstract (Gre-A) dimensions have various common characteristics, like Look at The Big Picture, Imagination, Endless Possibilities, Analyzing and Interpreting, Theoretical Connections, Logical Thinking, etc.
- A learner related to both Felder-Silverman's Global (FS-Gl) and Riding's Wholist (Rdi-W) dimensions has several common characteristics, like Holistic Thinking, Divergent Thinking, and Content Map.

Additionally, several common characteristics are related to several learning styles in different models. For instance, Gregorc's *Concrete-Sequential*, Honey and Mumford's *Theorist*, MBTI's *ISTJ* (Introvert-Sensing-Thinking-Judging), and Felder-Silverman's *Sensing-Active-Visual-Global* learning styles share a single characteristic named "Tangible Facts." Furthermore, several characteristics are also associated with both dimensions and learning styles at the same time. Also, the Honey and Mumford's *Theorist* learning style is characterized by the "Theoretical Connection" characteristic in Table 2, and related to MBTI's *Intuitive* (MB-IN), Kolb's *Abstract Conceptualization* (Kolb-AC) and Gregorc's *Abstract* dimensions (Gre-A), see Table 1.

Peter Honey and Alan Mumford developed four learning styles based on Kolb, with no clear dependence on basic dimensions, as do almost all the other learning style models. Honey and Mumford's learning style model and its' characteristics are interconnected. Table 2 gives the characteristics of various learning styles related to Honey and Mumford's learning style model. For example, the *Pragmatist* student prefers to be *Practical* and enjoys *Problem-Solving*. Similar mappings have been made for the other learning style models. In this way we established the interconnections between the learning style models dimensions, learning styles, and related characteristics.

4. The Learner's characteristics ontology

Ontologies have become a key enabling technology in several fields and are widely used in domains such as the semantic web, artificial intelligence and, in general, wherever there is a need to structure the concepts of a domain (Mellouli, Bouslama, & Akande, 2010). As defined by Gruber in 1993, an ontology is *"an explicit specification of a conceptualization"* (Gruber, 1993). In 1998, Staab &Studer refined this definition into *"an Ontology is a formal, explicit specification of a shared conceptualization"* (Staab & Studer, 2009).

From the perspective of e-learning, where there is no single model for either the learner's personality or content structure, the formal description of knowledge is important for integration and interoperability between models. Moreover, the explicit description of knowledge weakens the assumptions on the implicit nature of information (Rani, Nayak, & Vyas, 2015). In particular, using ontologies as tools for specifying the semantic interoperability of different learning style model characteristics could improve communication and interaction between computers and humans by specifying the semantics of learning style model characteristics used in the human-computer communication process.

4.1. Developing Learner's characteristics ontology

Developing an ontology from a conceptual model that represents a generalization of several models, like the one we introduced in Section 2.3, is a complex task. Sometimes, the knowledge implicitly makes the ontology formalization process difficult. Ontological Engineering provides several methodologies for creating the ontology in a complete and organized way. Several methods for ontology construction have been proposed in the past, as described in (Gómez-Pérez, Fernández-López, Corcho, 2004).

Our goal is to interconnect learning style model dimensions and learning styles with relevant learner's characteristics. In this work, we use the On-to-knowledge ontology development methodology (Sure, Staab, & Studer, 2009) to build the learner's characteristics ontology. This methodology has a Knowledge Meta Process, which consists of five phases. The feasibility study phase consists of identifying the resources. At the end of this phase, the developer must decide whether it possible to continue the development process or not. The kick-off phase is concerned with the establishment of the ontology requirements specification. It provides a semi-formal description of the ontology (using tables, conceptual maps and text). The refinement phase goal is to create an application-oriented target ontology according to the requirements specification produced before. Finally, the evaluation and maintenance phases serve as a proof for the correctness and usefulness of

Table 2
Characteristics of Honey and Mumford's learning styles.

Characteristics	Honey and Mumford's learning styles			
	Activist	Reflector	Theorist	Pragmatist
Here-and-Now Tasks	✗			
Brainstorming	✗			
Action Learning	✗			
Working in Small Groups	✗			
Collects data & Analyses		✗		
Observing and Thinking		✗		
Self-directed Learning		✗		
Cautious and Thoughtful		✗		
Theories & Facts			✗	
Theoretical Connections			✗	
Drawing information into a systematic and logical Theory			✗	
Complex Tasks			✗	
Trying out new Ideas and Theories				✗
Practical Applications				✗
Action Learning				✗
Problem-Solving				✗

Fig. 2. Partial view of the Learner's Characteristics Ontology.

the ontology. Then the ontology is deployed and can improve over time. In the rest of this section, we describe the steps followed to create the Learner's Characteristics Ontology.

4.1.1. Feasibility study phase

In this first phase, we identified several information resources related to learning style models. Many information resources are available on the Internet. To create the ontology, we collected information from studies available in scientific databases (ScienceDirect[3], IEEE Xplore[4], CiteSeer[x5], and Google Scholar[6]), Elsevier journals, and Springer journals.

A report by Coffield investigated the existence of 71 learning style models and defined a family of learning styles that contain approximately 53 models, 13 of which were evaluated in (Coffield et al., 2004). We chose the six models described in Section 3 according to two criteria: extensive usage in scientific research, and Curry's classification of learning styles (*Cognitive Personality, Information Processing,* and *Instructional Preferences*).

4.1.2. Kick-off phase

In this phase, we executed the learning characteristics extraction process, and the information that will be used in the ontology must be presented. A corpus of learner's characteristics selected from two perspectives: model dimension and learning style.

For each perspective, a group of characteristics related to one particular learning style model were extracted. The characteristics were then categorized by model dimension and learning style. For instance, the characteristics "*Imagination, Look at The Big Picture, Endless Possibilities, Analyzing and Interpreting, Theoretical Connections, Logical Thinking*" were grouped into *Felder-Silverman's Intuitive* (*FS-IN*) dimension (see Table 1). Similarly, the characteristics "*Complex Tasks, Theories & Facts, Analytical Reviewing, Drawing Information into a Systematic and Logical Theory*" were related to the *Theorist* learning style in Honey and Mumford's model.

These characteristics refer to several concepts with different relationships. The representation of these concepts and relationships and the construction of the learner's characteristics ontology are described in the next phases.

4.1.3. Refinement phase

The third phase of the Knowledge Meta process is *Refinement*, composed of three sub-phases:

- *Baseline taxonomy:* according to the initial specification obtained in previous phases, the baseline taxonomy is required to formulate application-oriented ontology initially. Fig. 2 shows a partial view of the learner's characteristic ontology.
- *Elicitation*: several knowledge entities were obtained from the *Kick-off* phase as follows:

[3] www.sciencedirect.com.
[4] www.ieeexplore.ieee.org.
[5] www.citeseerx.ist.psu.edu.
[6] www.scholar.google.com.

- The Learning Style Model (*Learning_Style_Model*) representing the six learning style models.
- The Model Dimension (*Dimensions*) specifying all dimensions related to each model.
- The Learning Style (*Learning-Style*) specifying all learning styles related to each model.
- The Pole (*Pole*) specifying all poles related to each dimension.
- Characteristics (*Characteristics*) containing all characteristics related to learning styles and dimensions.
- A shared Characteristic may be related to several Dimensions and/or several learning styles at the same time.

• *Formalization*: according to the specifications and the knowledge entities obtained above, ontological entities (*Concepts*) were organized in hierarchies. Fig. 3 shows the topmost-level Concepts of the ontology.

At the end of the *Refinement* phase, the main classes/concepts and relationships/properties were defined in the Learner's Characteristics Ontology. Consequently, the ontology obtained after this phase had to be encoded in a suitable ontology language.

We used the World Wide Web Consortium's Web Ontology Language[7] (OWL) (Hitzler, Krötzsch, Parsia, Patel-Schneider & Rudolph, 2012) for ontology encoding, and the Protégé[8] framework (http://protege.stanford.edu) for developing and maintaining ontologies. In OWL, the user can specify taxonomies for classes and properties. A class is interpreted as a set that contains individuals. The OWL Relationship/Property is a binary relation between two individuals. The property *is Characteristic Of* links the individual *Learning_Characteristics* to the individual *LS_Dimensions_Model* and *Learning_Style_Models*. We have defined the ontology classes (Fig. 3) and relationships between classes.

4.1.4. Evaluation and maintenance phase

Once the Learner's Characteristics Ontology had been built using OWL and checked via the standard Protégé reasoner, the Evaluation phase started. We applied several query examples to test the consistency and verify the usefulness of the proposed ontology. We used the DL Query[9] (a standard Protégé plug-in), which provides an easy-to-use feature for querying and searching in an ontology. Fig. 4 presents two query examples of the learner's characteristics related to the Kolb learning style. The first one shows characteristics related to a learner that has *Diverging* learning style as a dominant learning preference (see Fig. 4(a)). Several learners have a multi-learning style (bi- or tri-learning style). In the second query example, the learner's characteristics related to the Kolb *Converging* and *Diverging* learning styles are displayed (see Fig. 4(b)).

On the way to the development of a learning style model-independent authoring tool, we aim at bridging the gap between the different learning style models. We also plan a more exhaustive evaluation in the mid-term, when a prototype of the Learning Object Authoring Tool (LOAT) will be available. LOAT is a tool that enforces reuse, customization, and personalization to increase the efficacy of LO authoring processes (Labib, Carmen Penadés, Canós, & Gómez, 2015). Following the classical component content management system architecture, we are designing and implementing LOAT on top of three basic models: the Instructional Model, the Personalization Model (which contains the Learner's Characteristic Ontology) and the Product Line Model. Additionally, we integrate the Learner's Characteristic Ontology to help authors to create

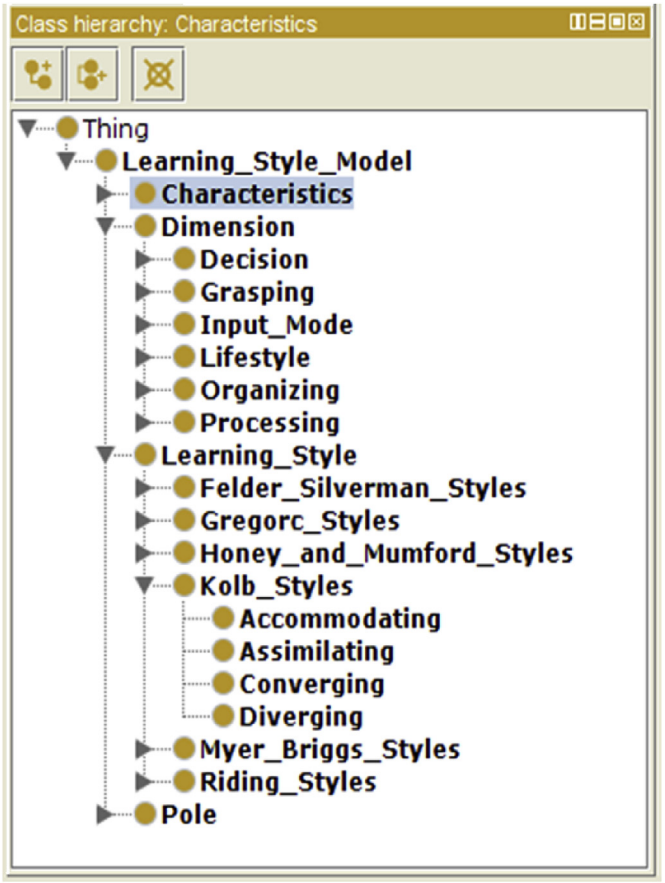

Fig. 3. The upper-level concepts.

learning materials that meet learners' characteristics and preferences. Upon this, we have great flexibility in reusing and producing mass personalized e-learning materials in different delivery formats.

To illustrate how the Learner's Characteristic Ontology can be exploited in LOAT, we use as an example of the initial steps of generating a learning object entitled "If Statement", which is part of an "Introduction to Java Programming" course. Initially, the author needs to fill the learning object metadata form, as shown in Fig. 5.

Later, the Personalization Model provides the author with an authoring guide that offers a catalog of learner's characteristics and learning activities that should be taken into consideration during the authoring process. Additionally, the Personalization Model recommends several components that related to the learning object's learning style or learning characteristics. Fig. 6 shows the learner characteristics and the recommended learning objects. Notice that two learning objects are recommended, one related to Kolb's Diverging and the other to Felder's Sensing-Reflective style which have similar characteristics.

5. Conclusions

Among the challenges associated with content personalization in e-learning systems, dealing with the heterogeneity of learning style models is a particularly complex task. With the aim of providing instructors with cross-model facilities, in this paper we have introduced a Learner's Characteristic Ontology which links the learning style model dimensions and learning styles with relevant learner's characteristics. The ontology was built following

[7] www.w3.org/OWL.
[8] www.protege.stanford.edu.
[9] www.protegewiki.stanford.edu/wiki/DLQueryTab.

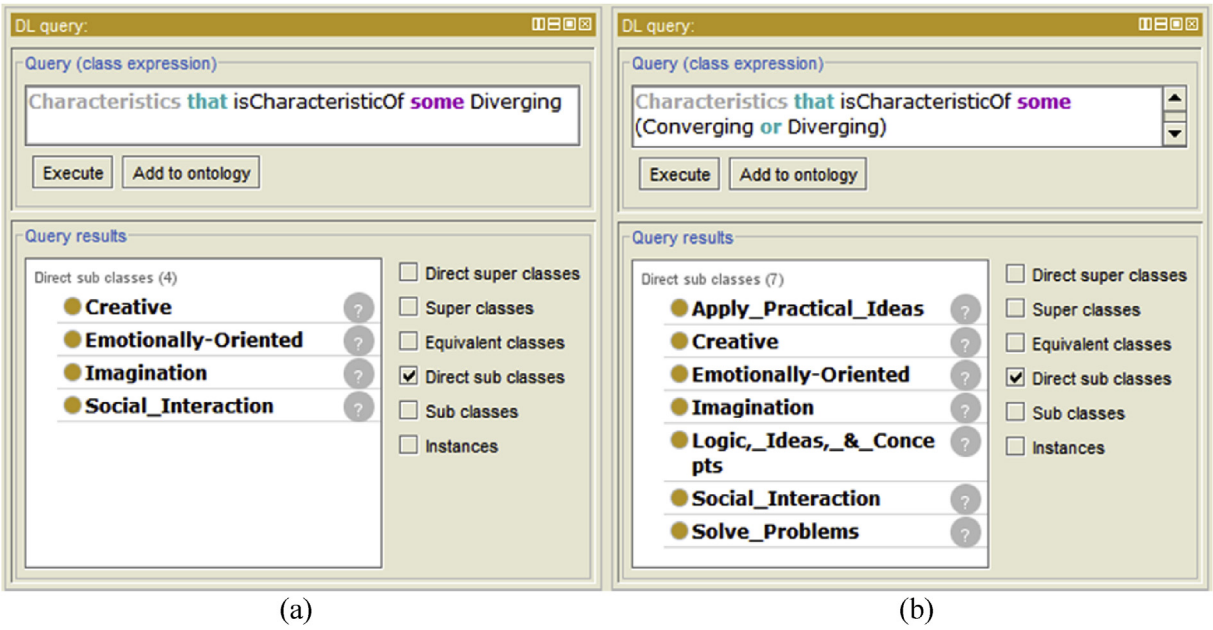

Fig. 4. Query examples. (a) For finding Learner's Characteristics of Diverging learning style. (b) For bi-learning styles (*Converging* and *Diverging*).

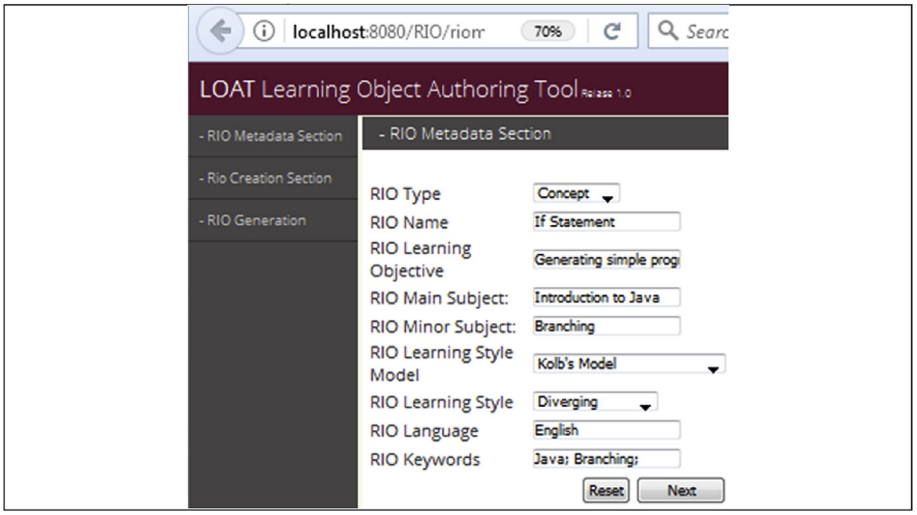

Fig. 5. Metadata form.

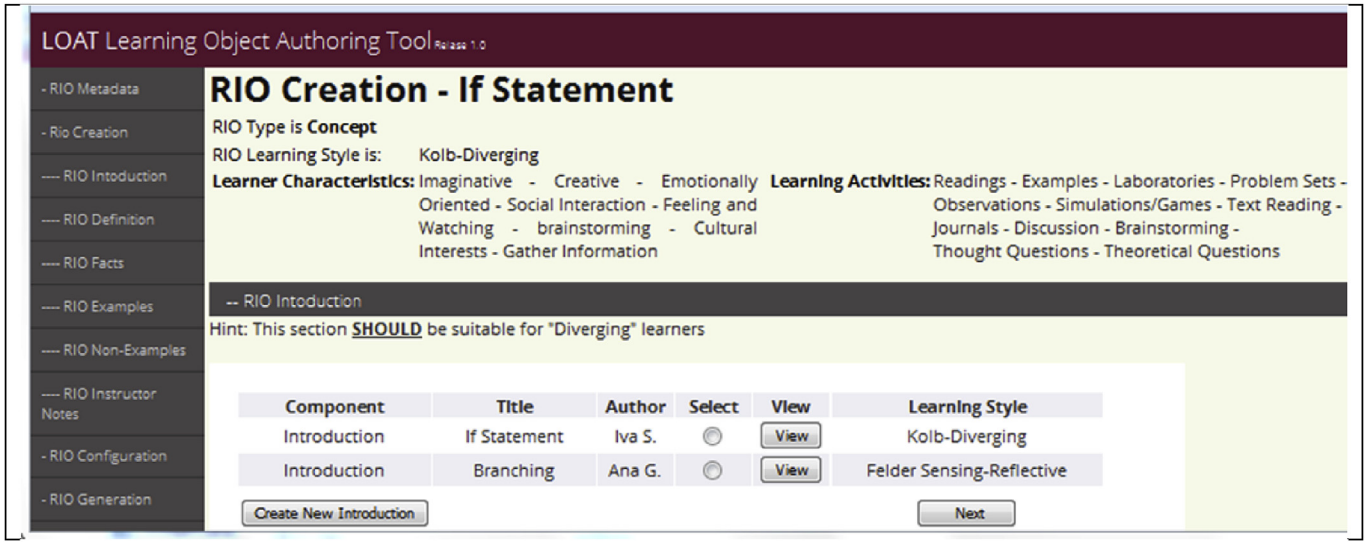

Fig. 6. The Learning Objects and Learner Characteristics recommendations.

the On-To-Knowledge methodology from the comparative study of six learning style models we selected according to different criteria. We have defined semantic relationships between concepts from different learning style models that will be the key for implementing semantic searches of learning materials developed following different learning style models. The learner's characteristics ontology is important for the instructor to semantically search for suitable contents during the learning content authoring process for the purpose of content reusability. A first prototype of semantically enriched authoring tool is the so-called Learning Object Authoring Tool (LOAT), first described in (Labib et al., 2015). It is aimed at providing real assistance to instructors in the learning materials authoring process with a high degree of content reuse and supporting different learner models.

A full-fledged LOAT is currently under development. Given the high number of learning style models, we plan to keep the ontology growing by incorporating new learning style models. We also plan to develop a content recommender utility as a complement of the semantic search mechanism. As a mid-term goal, we plan to develop an instructional environment complementary to LOAT that allows learners to take advantage of the semantic relationships in their autonomous learning processes.

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The work of J. H. Canós and M. C. Penadés is funded by the Spanish MINECO under grant CALPE (TIN2015-68608-R).

Appendix A

Characteristics

A1. Learning Style Model Dimensions Characteristics

Model	Dimension	Pole	Characteristic
Kolb	Grasping	Concrete Experience	Concrete Thinking
			Direct, Hands-on Experience
			Literal Manner
			Practical
			Realistic outlook
			Tangible Facts
			People Oriented
		Active Experimentation	Engage in Projects
			Experimentalists
			Working with Others in Groups
			An Active, Doing Approach
	Transforming	Abstract Conceptualization	Imagination
			Logical Thinking
			Look at The Big Picture
			Theoretical Connections
			Analytical
			Rational Evaluation
		Reflective Observation	Introspection
			A Tentative Approach to learning
			Observation of Others
			Theoreticians
			Introvert
MBTI	Gathering	Sensing	Natural Organizer
			Tactile
			Tangible Facts
			Realistic outlook
			Practical
			Literal Manner
			Attention to Details
		Intuitive	Saw the world in Endless Possibilities
			Integrated with Imagination
			Theoretical Connections
			Imagination
			Look at The Big Picture
	Decision	Thinking	Objective Decisions
			Use Analytical Logic
		Feeling	Subjective Decisions
			Interpersonal Interactions
			Search for Harmony
	Outside World Attitude	Judging	Planning
			Meeting Deadlines
			Decision-Making
			Organization
		Perceiving	Collect Information
			Spontaneity
			Adaptive and Flexible
	Life Attitude	Extravert	Social Interaction
			Applications
			Actions

(*continued*)

Model	Dimension	Pole	Characteristic
		Introvert	Reflective
			Isolated
			Working Quietly
			Independent Thinkers
			Concepts and Idea
			Introspection
Felder-Silverman	Perception	Sensing	Memorizing Facts
			Patient with Details
			Doing Hands-on Work
			Practical and Careful
			Concerned with Procedures
			Concrete Thinking
		Intuitive	Discovering Possibilities and Relationships
			Like Innovation
			Grasping New Concepts
			Abstractions and Mathematical Formulations
			Work Faster
	Processing	Active	Learning best by Doing
			Working with Others in Groups
			Experimentalists
		Reflective	Introspective processing
			Independent Work
			Theoreticians
			Prefers Thinking through Things
	Understanding	Sequential	Understanding in Linear Steps
			Learns in Small Incremental Steps
			Linear Thinking
			Orderly
		Global	Absorbing Material almost Randomly
			Holistic Thinking
			Learns in Intuitive Leaps
			See the Connections no one else sees
			Systems Thinkers
	Input Modality	Verbal	Prefers Written and Spoken Explanations
			Verbal Ability
		Visual	Prefers Visual Representations
			Visual Ability
Riding	Organizing and Processing	Wholist	Global View of Information
			Information is presented in Holistic
			Information is presented with a Content Map
			Tend to be Social
		Analytical	Information is presented in Parts
			Tend to be Isolated
			Interested in Details
	Information Mental Representation	Verbal	Prefers Textual/Verbal Information
			Tends to be Extraversion
		Imagery	Prefers Pictorial Information
			Tends to be Introversion
Gregorc	Perception	Concrete	Focus is on “Here and Now”
			Literal Manner
			Direct, Hands-on Experience
			Practical Applications
			Deal with Facts and Reality
		Abstract	Tends to be Intuitive
			Tends to be Imaginative
			Theories and Ideas
			Analyzing and Interpreting
			Thinking and Reflecting
	Ordering	Sequential	Deals with data in a Linear manner
			Deals with data in an Organized manner
			Plan things out Step-By-Step
			Bottom-up Learner
			Details
		Random	Information in Chunks, Skipping steps
			Non-Linear Approach
			Top-down Learner
			Makes Connections between Concepts and Ideas

A2. Honey & Mumford Learning Styles Characteristics

Learning Style	Characteristic
Activist	Here-and-Now Tasks
	Brainstorming
	Action Learning
	Working in Small Groups
	Experience-driven
	Open-minded
	Enthusiastic about new situations
	Try anything once
	Act first and consider the consequences afterwards
Reflector	Collects data & Analyses
	Observing and Thinking
	Self-directed Learning
	Cautious and Thoughtful
	Observing and listening to others
	Reviewing and pondering on experience
	Look at experience from different viewpoints
	Comprehensive compilation of information
Theorist	Theories & Facts
	Analytical Reviewing
	Drawing information into a systematic and logical Theory
	Complex Tasks
	Theoretical Connections
	Step-by-step upward logic
	Tend to be perfectionists
	Systematic thinking
	Independent
Pragmatist	Trying out new Ideas and Theories
	Practical Applications
	Action Learning
	Problem-Solving
	Put Ideas into Practice

Appendix B

Acronyms

Kolb-CE	Kolb - Concrete Experience
Kolb-AC	Kolb - Abstract Conceptualization
Kolb-RO	Kolb - Reflective Observation
Kolb-AE	Kolb - Active Experimentation
FS-S	Felder-Silverman - Sensing
FS-IN	Felder-Silverman - Intuitive
FS-A	Felder-Silverman - Active
FS-R	Felder-Silverman - Reflective
FS-Vi	Felder-Silverman - Visual
FS-Vr	Felder-Silverman - Verbal
FS-Sq	Felder-Silverman - Sequential
FS-Gl	Felder-Silverman - Global
Rid-W	Riding - Wholist
Rid-A	Riding - Analytical
Rid-Vr	Riding - Verbal
Rid-I	Riding - Imagery
MB-S	Myer-Briggs Type Indicator - Sensing
MB-IN	Myer-Briggs Type Indicator - Intuitive
MB-Th	Myer-Briggs Type Indicator - Thinking
MB-Fe	Myer-Briggs Type Indicator - Feeling
MB-Ext	Myer-Briggs Type Indicator - Extravert
MB-Intr	Myer-Briggs Type Indicator - Introvert
MB-Pr	Myer-Briggs Type Indicator - Perceiving
MB-Jd	Myer-Briggs Type Indicator - Judging
Gre-C	Gregorc - Concrete
Gre-A	Gregorc - Abstract
Gre-S	Gregorc - Sequential
Gre-R	Gregorc - Random

Appendix C. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.chb.2017.03.054.

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