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TOWARD PEDAGOGY-DRIVEN PERSONALIZED LEARNING EXPERIENCES IN CULTURAL DIGITAL LIBRARIES*

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Abstract. Cultural heritage institutions hold a vast amount of multimedia digital content forming a rich source of knowledge about cultural heritage, natural history, and biodiversity that could be used to serve various educational contexts and scenarios. However, due to a number of barriers, this knowledge remains largely unexploited. This paper addresses the problem and presents a framework and a service-oriented architecture for supporting personalized learning in cultural digital collections/libraries allowing: a) accessing and re-purposing existing multimedia digital content/archives for cultural digital objects, learning objects and higher learning units, and b) constructing pedagogy-

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driven personalized learning experiences in cultural digital collections statically or dynamically, taking into account different learner needs and preferences and instructional strategies encoded in educational templates. The proposed architecture also supports interoperability and sharing of cultural digital objects, learning objects and learning experiences with existing eLearning systems and large repositories/aggregators.

1. Introduction. In the last decade most cultural heritage institutions have been using digital resources. In addition to exact digital copies of their artifacts and specimens, cultural heritage institutions hold various types and formats of multimedia content that is used for educational purposes in the scope of the cultural heritage that is preserved in those spaces, such as simple text or hypertext, audios, videos, games and quizzes for children and adults, 2D and 3D visualizations, and even simulations. These digital resources form a rich source of knowledge about cultural heritage, natural history, and biodiversity that could be used to serve various educational contexts and scenarios, not only to support learning *about* the cultural heritage that is preserved in those institutions, but also learning *from* cultural heritage out of the scope of these institutions.

However, due to a number of barriers, an impressive abundance of multimedia content available remains largely unexploited. On one hand, digital resources in some institutions are still accessed in a limited way and used through rather static modes of delivery. On the other hand, there is a shortage of efficient support in existing digital libraries implementations for learning applications. One of the main challenges for a multimedia library is to provide effective access to its content and personalize the user's experience to fit his/her current goals and interests in the best possible way. From a Learner's user perspective this would mean accessing this information in a way that best fits his/her learning needs and preferences, including cognitive preferences (e. g., learning style). From a teacher or (museum) educator's user perspective this would mean to be able to access, use and "transform" this content to develop meaningful and effective learning experiences for different educational contexts and needs. These scenarios however are not efficiently supported in cultural digital libraries.

The goal of this paper is to provide a framework and an architecture for taking advantage of existing cultural digital materials residing in cultural heritage institutions to support the creation and provision of effective pedagogy-driven learning experiences not only in the context of the cultural heritage preserved in these institutions, but also to serve other learning contexts and scenarios. Specifically, from a stakeholder's/user's point of view: a) to support the needs of institutions preserving cultural heritage through opening their cultural collections to the learning community and their visitors and supporting effectively formal and informal learning applications in them; b) to support educators and teachers accessing cultural digital content residing in those institutions collections and developing learning experiences to effectively support the needs of different learners in a pedagogically-sound way maximizing the learning outcome; and c) to support Learners with different needs and preferences accessing cultural material in an effective pedagogy-driven personalized way.

2. From digital content and objects to learning experiences. A digital library mediates between the information needs of its user community and the globally available content. This is achieved by contributions in four areas [29]:

- Content pre-selection: The library selects high-quality content potentially relevant for the members of its user community.
- Content structuring: The library structures the content according to the pre-dominant domain understanding of its user community.
- Content enrichment: Domain and library experts as well as community members enrich content objects with descriptive and value-adding metadata.
- Library services: Services for content retrieval, access, annotation, etc. sup-port the identification of relevant material and facilitate access to content.

The basic elements in these structures are digital objects. In the broad sense, a digital object is an information object that has a digital form and is described with metadata: descriptive, administrative and structural. Any object, physical or digital, can be described and discussed in possibly infinite ways, depending on the context. This depends on the perspective from which one approaches the digital object (e. g., cultural, historical, artistic, etc.). The choice of metadata terms used to describe the content of a digital object in any collection is (and has to be) based on implicit or explicit assumptions or beliefs about how, when and where the asset is likely to be used and by whom [33]. Different metadata models have emerged in order to be able to describe different aspects of digital objects and contextualize them depending on the intended use of those objects.

On the other hand, in eLearning environments the material is cut into smaller independent pieces that can be used as they are or in combination with other material to form higher level objects covering the learning needs of the users on demand at any place and at the right time. The fundamental idea behind learning objects is that instructional designers can build small instructional components that can be reused in different learning contexts [37]. There is a common consensus that a learning object should be Reusable, Accessible, Interoperable/portable and Durable (RAID). An important aspect for reusability and personalization is the granularity of learning objects. However the structure and composite nature of a learning object is still open to interpretation [7]. Different content models have emerged in order to address this problem [7].

The Learnativity Content Model [36] adopted in the framework presented in this paper illustrates the concept of assembling content into higher-level objects (Fig. 1).

The basic components of the Learnativity content model are the following [36]:

- Content Asset: Content Assets include raw media such as images, text snippets, audio clips, applets, etc.
- Information Object: A text passage, Web page(s), applet, etc. that focusses on a single piece of information. It might explain a concept, illustrate a principle, or describe a process.

- Learning Object: A collection of Information Objects that are assembled to teach a single learning objective.
- Learning Component: A Learning Component is a generic term for things like lessons and courses which are typically connected with a higher level learning objective and have multiple learning objectives since they are composed of multiple Learning Objects.
- Learning Environment: A catch-all phase for the combination of content and technology with which a learner interacts. A combination of learning components with communication tools and/or other features that facilitate an e-learning experience can be aggregated into a learning environment (e. g., LMS).

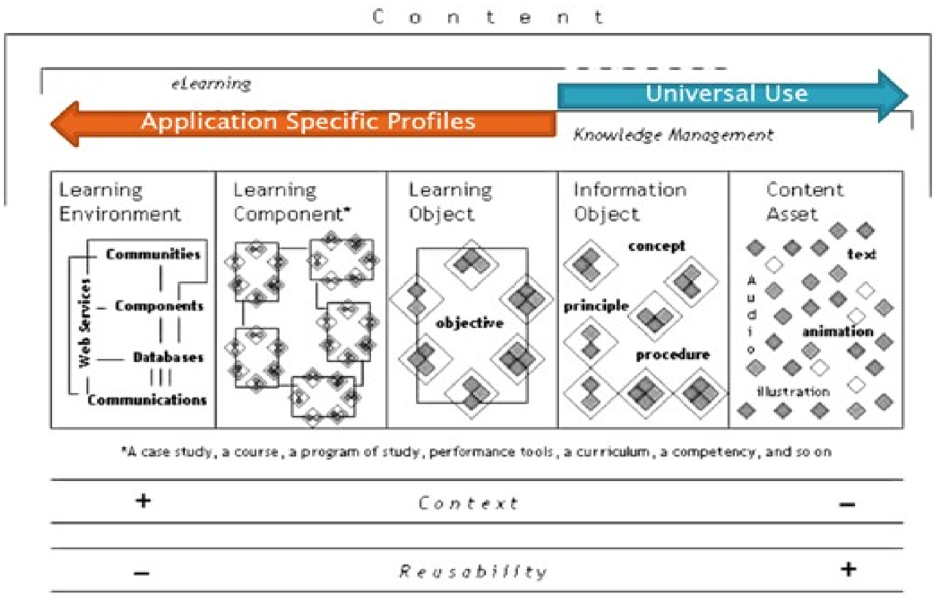

Fig. 1. The Learnativity content model [36]

For the purposes of this paper and in the context of cultural heritage we will use the term Cultural Digital Objects to refer to objects at the level of information objects. We will also use the term Learning Experience residing at the level of Learning Components to refer to structured learning activities with specific objectives that can be supported by Learning Objects (or services) which a Learner experiences to accomplish a target learning goal.

3. Interoperability of (cultural) digital libraries and eLearning applications. Ouksel and Sheth identify four types of heterogeneity which correspond to four types of potential interoperability [30]: system (incompatibilities between hardware and operating systems), syntactic (differences in encodings and representation), structural (variances in data-models, data structures and schemas), and semantic (inconsistencies in terminology and meanings). To support eLearning applications in museums' cultural collections we have to deal with challenges related with all the above interoperability types, making this a complex and multilevel problem.

We can also define two axes of interoperability based on the layers of objects defined in the Learnativity model as presented in Fig. 2:

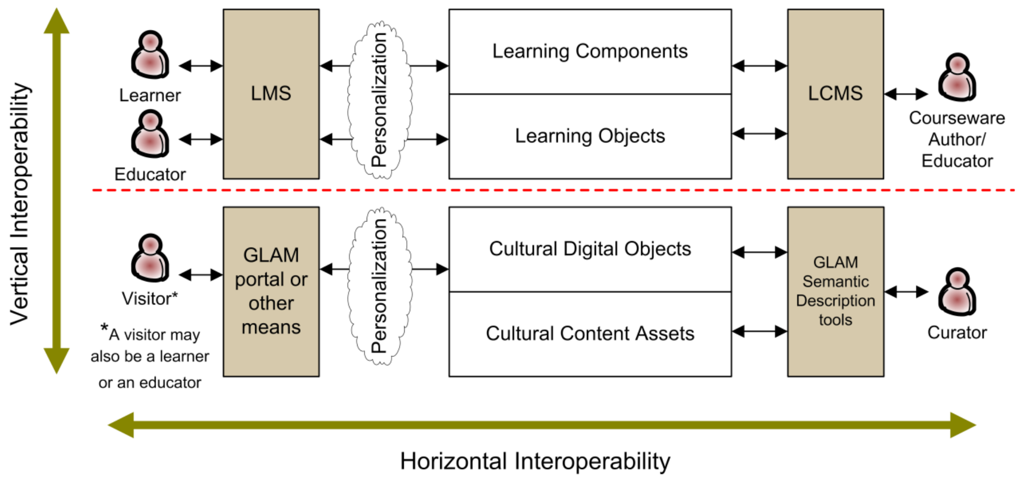

Fig. 2. Horizontal and vertical interoperability

- Horizontal Interoperability: Access and use of objects at the same level, and
- Vertical Interoperability: Access, use and "transform" objects at one level to build objects at a higher level (re-purposing, contextualization).

Interoperability on both axes can be seen from the point of view of objects, standards, infrastructures, users and personalization [1, 35].

Much work has been done to achieve “horizontal” interoperability at the level of cultural content assets and objects in terms of standards and projects. Reports in the context of ATHENA [21], MINERVA [13] and PrestPRIME [32] projects provide extensive surveys on standards, specifications and guidelines for the description, preservation and access of (cultural) digital objects. In addition to these projects, other important projects launched to propose digital platforms and provide access to cultural digital content are ECHO—European Cultural Heritage Online Initiative, CAN, and Google Art Project [14]. One of the most important EU-funded project is Europeana.eu, which is the most well-known portal for exploring the digital resources of Europe’s museums, libraries, archives and audiovisual collections, thus offering direct access to millions of books, manuscripts, paintings, films, museum objects and archival records that have been digitized throughout Europe. An increasing number of Europeana-related projects listed on Europeana.eu web site [12] support or aim to support inter-connection of cultural heritage institutions collections and interoperability with Europeana.eu.

The work presented in this paper mainly deals with the vertical axis (supporting effective learning applications in cultural/multimedia collections/libraries), also taking into account the related standards and work to support horizontal interoperability at each level. From the perspective of cultural digital libraries, cultural digital resources are ingested and annotated by curators using different standards or non-standard schemes and/or domain ontologies, taxonomies or vocabularies. To be able to support learning, these cultural digital objects should first be re-purposed to create learning objects and further used for the development of higher learning units to be delivered in the form of learning experiences. This is not a straightforward process, e. g., a one-to-one mapping process between the corresponding digital library and e-learning standards [35]. A digital object cannot become a learning object (LO) unless it has a clear pedagogical purpose (learning outcome/objective) that is appropriately linked to the object through learning metadata and the right granularity and content for the target pedagogical purpose. However, we cannot predict all possible educational uses of digital objects. Afterwards, these LOs should be assembled into higher level learning units (Learning Components) and delivered to learners as learning experiences in the best possible way that depends on the current learning context and needs. On one hand this repurposing process is not efficiently supported in cultural digital libraries and on the other hand museum staff, but also teachers out of the scope of these museums, lack the pedagogical knowledge to develop learning objects and learning experiences to effectively support the needs and preferences of different Learners. Effective personalized learning services are needed allowing the creation and delivery of personalized learning experiences to Learners taking into account their individual learning needs and preferences.

Successful projects dealing with interoperability of cultural/multimedia digital collections and support of personalized learning services in them include LOGOS [4, 5, 27], Natural Europe [22, 23, 24, 28], and Share.TEC [34].

The LOGOS project developed a Knowledge-on-Demand ubiquitous learning platform, providing effective personalized learning services to support learning anywhere, anytime in existing multimedia archives, exploiting alternative delivery channels and related devices that go beyond the traditional web-based learning approaches. One of the application domains of this project was Bulgarian Iconography.

The Natural Europe project aimed at taking advantage of Natural History Museums' content by making it available online and using it to create meaningful educational experiences within the museums themselves. Natural Europe's aim was to offer to the museums the tools that will allow them to continuously manage and publish their digital collections online. The project exposed this cultural content from NHMs in Europe, to Europeana. This content is being used to develop educational pathways that visitors can use to navigate both physically and virtually through NHM exhibitions, connecting them with the school curriculum.

The Share.TEC project's objective was to provide a platform, called Share.TEC system, for unified access to digital resources in the domain of Teacher Education (TE). The Share.TEC system's goal was to establish a highly visible and functional portal with advanced brokerage services that will provide personalized access to a wide-range of Teacher Education (TE) content.

The research project No. DN02/06/15.12.2016 "Concepts and Models for Innovation Ecosystems of Digital Cultural Assets" (2016–2018) funded by the Bulgarian Science Fund deals among others with creating models and tools for improved use, research and delivery of digital cultural resources including support for learning applications in them.

4. Personalization in digital libraries. The DELOS/NSF Working Group on Personalization and Recommender Systems for Digital Libraries defines personalization as "the ways in which information and services can be tailored to match the unique and specific needs of an individual or a community" [9]. This is achieved by adapting presentation, content, and/or services based on a person's task, background, history, device, information needs, location, etc., essentially the user's context". Most often the personalization techniques in DLs include the selection and recommendation of information resources, system interfaces and the means of navigation according to the personal characteristics of the user (demographic status, goals, tasks, skills, motivation, achievements, interests/disinterest, preferences, requirements, etc.) on one hand, and according to the user's behavior in the environment on the other—a solution specified as personalization according to a user profile [6].

User modeling can be defined as the process of acquiring knowledge about the user in order to provide services, adaptive and personalized information flow/s following its specific requirements in the DL domain. The main questions asked are about the user's interests, preferences, goal and intents, motivation, experience and activities [6]. Building a user model for a DL involves defining: the "who" (the degree of specialization); the "what" (the cognitive goals, plans, attitudes, capabilities, knowledge, and beliefs of the user); the "how" (the model is to be acquired and maintained); and the "why" (whether to elicit information from the user, give assistance, provide feedback, or interpret the user's behavior) [6].

When the user is a learner, there are a number of factors that can positively affect learning, including the learning style, the learner's goals/objectives, previous knowledge, educational level and difficulty, technical and other preferences [1, 6].

The representation of the learner model can follow developed standards and specifications (e. g., IEEE Personal and Private Information—PAPI and IMS Learner Information Package—LIP), maximizing its reusability and portability.

5. Pedagogy-driven personalization. Different learners have different learning needs and preferences, thus they need different workflows of "how and what" is taught to learn best, while in parallel they may need to master different objectives in order to achieve the same learning goals. To this end it is important to take into account pedagogy to support personalization. Instructional Design is an engineering activity for which the artifact is some instructional product to help a learner acquire some knowledge or skill [25]. However, the instructional design process is usually performed completely by regular teachers lacking advanced pedagogical skills, resulting in scenarios where a sound pedagogical approach (the "how") is absent and the focus is mainly on "what" to teach, putting the learners and their individual learning needs on the side-lines.

If we could let instructional design experts to design the "missing part" (the "how"), this would help the teachers, educators and training professionals to design effective, efficient and appealing instruction that meets the requirements of specific learning goals, learners' characteristics and organizational needs. Instructional designers could create pedagogical patterns (educational templates without specific learning content), as prescriptions for designing instructional products to optimize the learning outcome capturing best practices in particular educational domains [11]. Based on these patterns (educational templates), teachers or adaptive systems can create learning scenarios for various educational contexts.

In this paper we will refer to "pedagogy-driven personalization" as the application of instructional strategies to personalize the learners' experience taking into account their individual characteristics, needs, and preferences (e. g., goals, learning style, previous knowledge, educational level etc.), which affects structuring of learning activities and content selection.

6. Adaptive Learning Systems. Within the field of technology-enhanced learning, adaptive learning systems offer an advanced form of learning environment that attempts to meet the need of different students. Such systems build a model of the student's knowledge, goals and preferences and use the generated model to dynamically adapt the learning environment for each student in a manner that best supports learning [8]. Strategies that have been used to adapt to these learner characteristics include annotating links, hiding links, changing the sequence of material and hiding or tailoring the content [8].

To describe adaptive learning systems, one may distinguish between the following major concepts: the domain model, the learner model, the context model, the instruction model, and the adaptation model. In several of them the instructional model is bound with the domain model (content) or the adaptation model (adaptation engine). In these cases, adding new or different pedagogical models to the content model and/or the adaptation model is more difficult and involves a re-authoring of the content model and/or the adaptation model. Other shortcomings found in several adaptive learning systems analyzed in [1] are:

- Pedagogy (the how-to-teach) is not always taken into account. Although adaptivity in eLearning has become one of the key aspects in Adaptive Learning Systems, such adaptivity has tended to focus on adaptive content retrieval and (simple) content sequencing based on domain models, or more recently ontologies [10].
- The systems are dependent on a specific learning style approach that is bound with the adaptation strategy (algorithm) or the domain model. This leads to lack of generality, i. e., of capability of the system to support other learning style approaches.
- The systems have fixed knowledge domains which are not easily expandable or adaptable to other subject matter.
- The complexity, cost and effort required to develop adaptive eLearning experiences is very high.

The framework presented in this paper clearly separates the instructional model from the domain model and adaptation model in order to support reusability of abstract training scenarios and different combinations with content in various learning situations.

7. Modeling the environment to support pedagogy-driven personalization. In this chapter, the modeling of the environment is described in order to support repurposing of cultural digital content to pedagogically-sound personalized learning experiences in a static or dynamic (adaptive) way [1, 2, 3, 4, 5]. Towards this end it defines and describes the following models: the domain model, the learner model, the instructional model and the adaptation model.

Domain modeling—Following the Learnativity Model it was stated how learning experiences can be gradually developed from digital content assets coming from multimedia archives. Such a categorization is important to define the granularity of these objects and their characteristics to support personalization. The detailed representation of these objects and their relations was developed using the METS digital library standard [26] as the basis for combining various schemata necessary to describe Digital Objects (DOs), reusable Learning Objects (LOs), Assessment Objects (AOs) and Learning Components (LCs), as illustrated in Fig. 3. The use of METS to support the hierarchical approach in the categorization and development of objects allows for: a) integrated description of objects at each level using several appropriate (metadata) schemes to represent the different aspects of objects, b) references to objects residing at lower levels without repeating their information at the current level, and c) appropriate adaptation/transformation of objects at run-time in order to support cross-media delivery of learning experiences.

In order to support pedagogy-driven personalization as proposed in this framework it is important to consider some pedagogical properties of the description of Learning Objects and Assessment Objects. Learning Objects are built in order to fulfill certain learning objectives, while Assessment Objects are built and used to assess the satisfaction of certain learning objectives (previous knowledge). Learning Objectives of Learning/Assessment Objects are defined as pairs consisting of a verb taken from Bloom's taxonomy and a topic referencing a concept or individual from a domain ontology using LOM classification element. Similarly, the classification element of LOM can be used for the intended educational level of Learning Objects. The difficulty and the provider of a Learning Object are represented in the educational.difficulty and lifecycle.contribute elements of LOM, respectively.

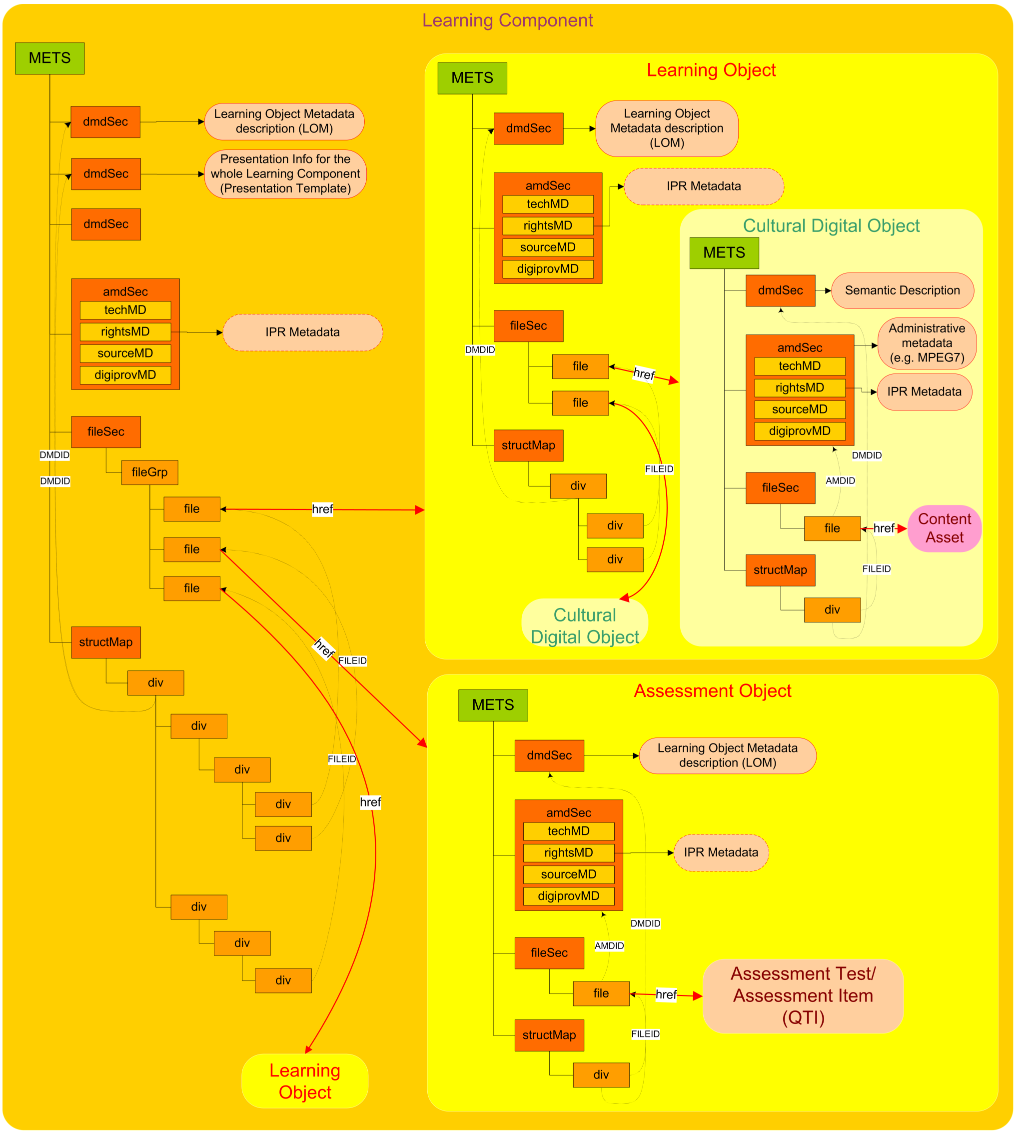

Fig. 3. Representation of LCs, LOs, AOs, CDOs and Content Assets and their relations using METS

In order to support different learning styles and perform adaptive selection of learning objects, this framework uses the following elements under the LOM *educational* element: learningResourceType, interactivityType, interactivityLevel, and semanticDensity, in addition to the learning objective as described before using a classification element. This way, learning objects remain independent from the learning style approach used and can be re-used to support different learning style categorizations and learning scenarios. This is an advantage of this framework in contrast with other approaches where the learning style value for which a learning object is appropriate has been incorporated in its metadata prohibiting the exploitation of those learning objects to support other learning style categorizations. The important metadata for Assessments are the learning Resource Type (=exercise for Assessment Items, =questionnaire for Assessment Tests), the Learning Objective (expressed via classification element), the difficulty and the educational level.

Learner modeling—The parameters described in Chapter 4 as important to personalization processes and their relations are normalized within the conceptual model illustrated in [3]. These can be considered as a part of a Learner Profile, since they describe in some extent a Learner. A Learner Profile may contain more information, but here we focus on what is considered as important in this framework for the dynamic creation of personalized learning experiences.

Most Learners are unaware of their learning styles and the various approaches/views of them. Thus, in most learning style approaches, a corresponding assessment instrument in the form of a questionnaire is provided, so that is it possible to detect the learning style of a Learner [20]. This assessment instrument, after its completion by the Learner, will reveal the Learner's dominant learning style(s) according to the current (for every time) learning style approach. For example, the Honey and Mumford Learning Style Questionnaire can be used for the identification of the Learning Style of the Learner according to Honey and Mumford's classification [15]. However, this questionnaire is quite long: it contains 80 questions. IBM used a shortened version to investigate the learning styles of 365 of their managers [15].

It should be noted here that the use of the dominant learning style(s) of the Learner revealed from these instruments in the personalization process should not be restrictive and the Learner is allowed to change this parameter and "taste" learning experiences for different learning styles if (s)he wants to.

Instructional modeling—The pedagogy-driven personalization is based on abstract training scenarios (educational templates or Learning Designs) encoding instructional strategies in training methods as prescriptions for the development of learning experiences to teach specific subjects, taking into account the individual learning styles, educational level, preferred difficulty and other preferences of the learners. Learning objects are not bound to these scenarios at design time, but only their characteristics are defined. The definition and representation of these educational templates is based on a specific instructional ontology [3] that takes into account related standards, such as IMS LD [18].

These abstract training scenarios can be exploited for the development of personalized learning experiences in a static or (automatic) adaptive way. In the first case, the educator imports these templates and uses them as a guide for the manual development of learning experiences. In the second case, an adaptation mechanism (adaptation model) is applied to automatically construct personalized learning experiences taking into account the current context, learning needs and preferences encoded in Learner model and selecting an appropriate training method from these templates to be used thereafter to find and bind appropriate learning objects to the learning activities, as presented in the following section.

Learning styles affect both the construction of the learning plan and the selection of learning objects and this are highly dependent on the taxonomy that is used in a specific environment for the definition of learning styles. For the Honey and Mumford learning styles tested in this framework Papanikolaou et al. [31] propose the following instructional strategies:

- activity-oriented with high interactivity level for activists, who are more motivated by experimentation and challenging tasks;
- example-oriented for reflectors who tend to collect and analyze data before taking action;

- exercise-oriented for pragmatists, as they are keen on trying out ideas, theories and techniques;
- theory-oriented for theorists, giving them the chance to explore and discover concepts in more abstract ways.

Adaptation modeling—The adaptation process is encapsulated in an appropriate personalization algorithm that takes into account the knowledge provided in the Learner model and the available educational templates to dynamically create personalized learning experiences, as presented in Fig. 4. Specifically, the goal is to find an appropriate Training Method of an educational template that will be used thereafter to construct a learning experience adapted to the Learner's needs. After this method is found, its structure is refined taking into account the previous knowledge of the Learner to remove activity structures or activities with learning objectives that have been mastered by the Learner. Finally, appropriate Learning Objects are retrieved to be bound to the learning activities of the resulting structure.

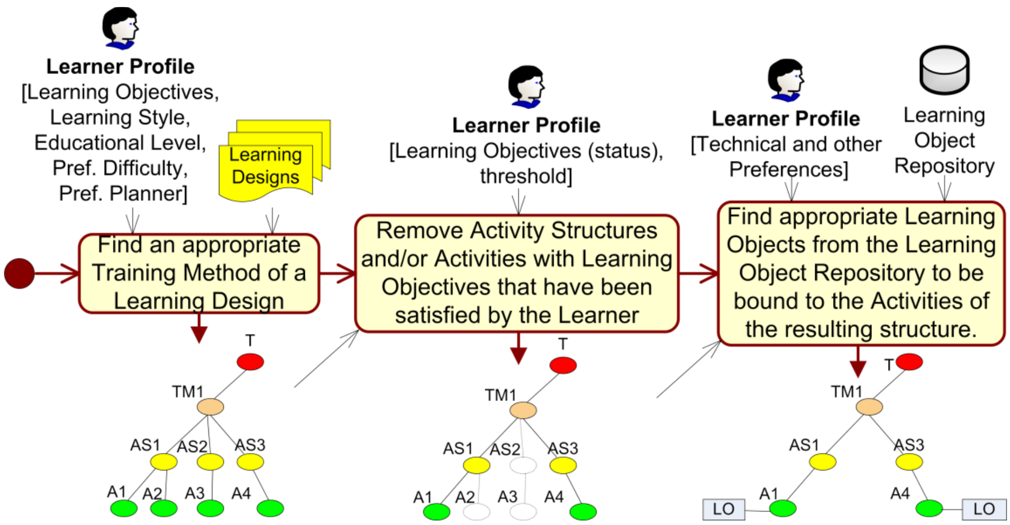

Fig. 4. The procedure for the dynamic creation of personalized learning experiences

To find an appropriate Training Method, the existing Training Methods are ranked using the following formula:

$$w_{TM} = a_{LV} \cdot w_{LV} + a_{LS} \cdot w_{LS} + a_{EL} \cdot w_{EL} + a_D \cdot w_D + a_P \cdot w_P ,$$

where:

$$a_{LV} + a_{LS} + a_{EL} + a_D + a_P = 1$$

w_{LV} is a weight in [0, 1] representing the degree of satisfaction of Learner's Learning Goals from the Learning Objectives associated (indirectly) with the Training Method. That includes the Learning Objective of its parent Training and the Learning Objectives of its Activity Structures and Activities. This weight is computed as follows:

$$w_{LV} = \frac{\sum_{i=1}^{n} p_i}{n},$$

where $p_1, \ldots, p_n$ are the priorities of the Learning Goals of the Learner taking into account only those Learning Goals that correspond to Learning Objectives associated with the Training Method.

w_{LS} is 1 if the Training Method's associated Learning Style matches the Learning Style of the Learner and 0 otherwise.

w_{EL} is a weight in [0, 1] representing the degree of similarity between the Educational Level of the Training Method and the Learner's preferred Educational Level. To compute this weight, we assume that the different (ordered) textual values of the Educational Level are mapped to [0, 1] so that higher Educational Level values are closer to 1. The simplest way to achieve this is to map the lowest Educational Level to 0, map the higher Educational Level to 1 and all intermediate values are mapped uniformly in [0, 1] with distance between two successive values equal to $1/(n-1)$ where n is the total number of distinct Educational Level values.

Then, w_{EL} can be computed as follows:

$$w_{EL} = 1 - \left(|e_P - e_{TM}| + e_P \cdot f\left(e_{TM} - e_P\right) \right),$$

where e_P is the preferred Educational Level of the Learner (the one stored in his profile), e_{TM} is the Educational Level of the Training Method, and f is a function defined as:

$$f(x) = \begin{Bmatrix} 0, & x \le 0 \\ 1, & x > 0 \end{Bmatrix}.$$

The above formula is based on the assumption that Educational Levels that are lower than the preferred Educational Level of the Learner are more appropriate than higher Educational Levels.

w_D is a weight in [0, 1] representing the degree of similarity between the Difficulty of the Training Method and the Learner's preferred Difficulty. To compute this weight, we assume that the different (ordered) textual values of Difficulty are mapped to [0, 1] so that higher Difficulty values are closer to 1. The simplest way to achieve this is to map the lowest difficulty to 0, map the higher difficulty to 1 and all intermediate values are mapped uniformly in [0, 1] with distance between two successive values equal to $1/(n-1)$ where n is the total number of distinct Difficulty values. Then, w_D can be computed as follows:

$$w_D = 1 - \left(\left| d_P - d_{TM} \right| + d_P \cdot f\left(d_{TM} - d_P \right) \right)$$

where d_P is the preferred Difficulty of the Learner (the one stored in his profile), d_{TM} is the difficulty of the Training Method, and f is a function defined as:

$$f(x) = \begin{Bmatrix} 0, & x \leq 0 \\ 1, & x > 0 \end{Bmatrix}.$$

The above formula is based on the assumption that Difficulty levels that are lower than the preferred Difficulty of the Learner are more appropriate than higher Difficulty levels.

w_P is 1 if the Training Method's Planner (i. e., the one associated with its parent Training) is one of the Learner's preferred Planners and 0 otherwise.

When an appropriate Training Method is found its structure is further refined, by removing from it Activity Structures and Activities with Learning Objectives that have been satisfied by the Learner (the Learner can define a threshold value *t*, so that Learning Objectives with satisfaction value greater than *t* be considered as satisfied).

The next step is to retrieve appropriate learning objects to be bound to the activities of the refined training method structure. The selection is based on the properties described in the Learning Object Type (LOT) of each activity and other preferences of the Learner. In order to submit the query with the total learning object requirements, fuzzy filters are used.

To describe the evaluation of queries in this model we assume that F is an evaluation function $F: Q \times O \rightarrow [0,1]$ that gives a value from [0, 1] to any valid query $q \in Q$ for each Learning Object $o \in O$. This function is defined recursively as follows:

$$F(\langle t_1, w_1 \rangle OR \ldots OR \langle t_N, w_N \rangle, o) = \left(\frac{\sum_{i=1}^{N} F(t_i, o)^p \cdot w_i^p}{\sum_{i=1}^{N} w_i^p} \right)^{1/p}$$

$$F(\langle t_1, w_1 \rangle AND \ldots AND \langle t_N, w_N \rangle, o) = 1 - \left(\frac{\sum_{i=1}^{N} (1 - F(t_i, o))^p \cdot w_i^p}{\sum_{i=1}^{N} w_i^p} \right)^{1/p}$$

$$F(NOT\ t, o) = 1 - F(t, o)$$

$$F(condition_{on_{LOM_{element}}} >, o) = \left\{ \begin{matrix} 1, \ if\ the\ condition\ is\ true\ for\ o \\ 0\ ,\ otherwise \end{matrix} \right\}$$

An example of the fuzzy filter that is used for the retrieval of appropriate learning objects for an activity is given in Fig. 5. The weights on the LTerm nodes have been appropriately selected in order to retrieve only learning objects that at least satisfy the Leaning Objective of the current activity.

The generated learning experience is stored as a Learning Component and can be further transformed to a SCORM package for its delivery to eLearning systems.

The algorithm presented can be used in a similar way for the creation of Assessment Tests in order to evaluate the previous knowledge of the Learner and update his/her Learner profile. Specifically, the Training Method that has been selected according to the target goals of the Learner is used for the construction of an appropriate test in order to evaluate the knowledge of the Learner in the specific sub-domain, whose scope is defined through the training method's associated learning objectives. The goal is to find appropriate

Assessment Objects (Assessment Items or Assessment Tests) that will be bound to the training method's activities forming a test that will be able to evaluate to what extent the Learner has mastered the associated learning objectives. This way, the Learner Profile will be updated either by updating the status of existing Learning Objectives or by adding new Learning Objectives and their corresponding status values that may not exist in his/her profile.

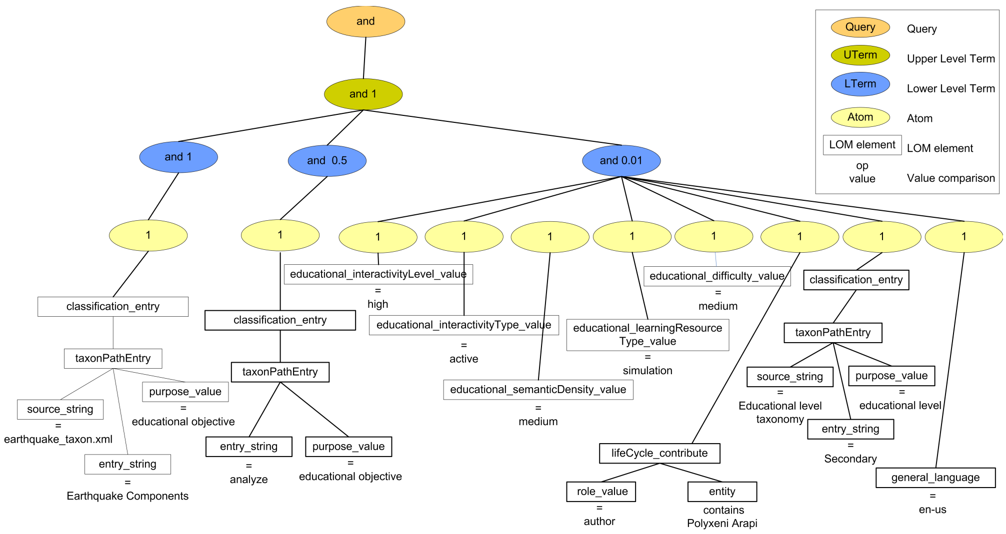

Fig. 5. Example of a fuzzy filter used for the retrieval of appropriate learning objects for an activity

8. Architecture. In this chapter, an integrated service-oriented architecture is presented implementing the models presented in the previous chapter. The architecture illustrated in Fig. 6 exploits widely accepted standards and protocols and integrates repositories, tools and other components to support access, use and re-purposing of the cultural digital content residing in cultural heritage institutions for the development of pedagogy-driven personalized learning experiences to support different learning needs and contexts. An integral part of this architecture are components to support the development of pedagogically-driven personalized learning experiences statically or dynamically, as they have been modeled and described in the previous chapter.

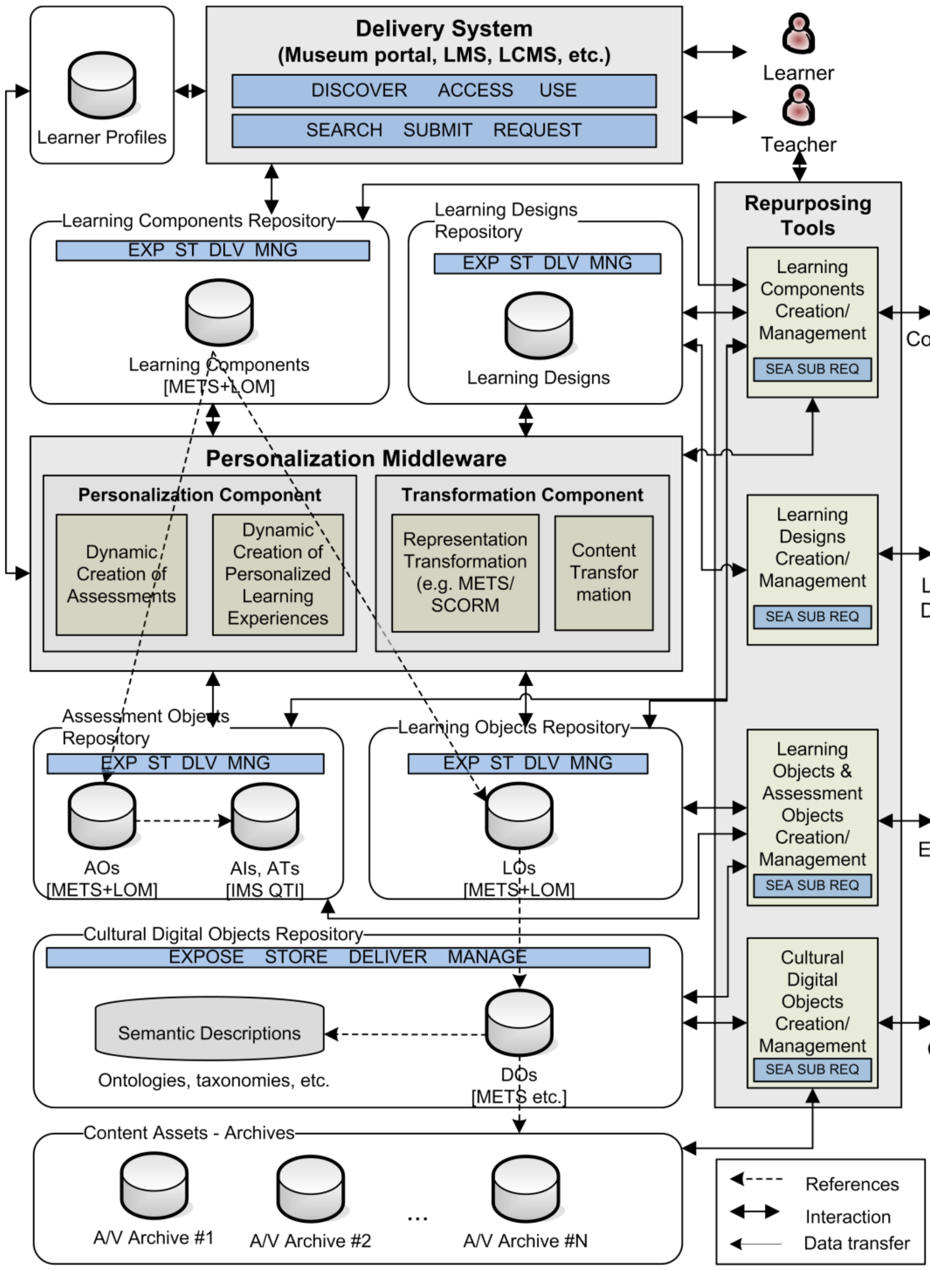

Fig. 6. Architecture

From a user's point of view, the architecture allows: a) museum educators and teachers to find, use and repurpose cultural digital objects to learning objects and to higher-level objects in order to develop pedagogically-sound personalized learning experiences to fit the needs of different learners, b) instructional design experts to develop reusable pedagogical templates, encoding instructional strategies in order to help museum educators and teachers develop pedagogically-sound personalized learning experiences, c) learners access learning objects and higher level learning units developed by museum educators and teachers and be provided with personalized learning experiences fitting their individual needs and preferences.

The architecture follows the recommendations of the IMS Digital Repositories Interoperability (IMS DRI) specification [17] for the interoperation of the most common repository functions enabling diverse components to communicate with one another: search/expose, submit/store, gather/expose and request/deliver.

The architecture consists of the following components:

- Appropriate *repositories and services* for the management of the objects according to the domain model described in Chapter 7: Content Assets, Cultural Digital Objects (CDOs), Learning Objects (LOs), Assessment Objects (AOs) and Learning Components (LCs). Interoperability and sharing of cultural digital objects, learning objects and learning experiences with existing large repositories/aggregators can be supported with the implementation of OAI-PMH (gather/expose function in terms of IMS DRI).
- *Repurposing tools* for the creation and editing of the above types of objects as well as for the creation of abstract training scenarios (Learning Designs) according to the instructional model presented in order to support the creation of pedagogically-sound personalized learning experiences.
- The *Personalization Middleware*, responsible for the dynamic creation of personalized learning experiences and assessment tests and their transformation to SCORM format to be delivered to eLearning

applications based on the adaptation model presented. The middleware consists of:

- The *Personalization Component* used for the Dynamic Creation of Personalized Learning Experiences according to specific learning needs expressed in Learner Profiles (including the concepts of the Learner model presented) and using a set of abstract training scenarios (Learning Designs). The Personalization Component also encapsulates functionality for the Dynamic Creation of Assessments from Assessment Objects in order to "measure" the previous knowledge of the Learner and update his/her Learner Profile.
- The *Transformation Component*, which is responsible for the trans-formation of the objects' METS-based descriptions to SCORM Content Packages. This includes not only simple transformation from METS XML file to SCORM manifest file, but also the construction of the whole SCORM package (PIF).

• *Delivery systems* (Software Agents in terms of IMS DRI, e. g., museum portals, Learning (Content) Learning Management Systems etc.) that discover access and use the content of the digital library through appropriate services (resource users). Learning Management Systems in this framework include components encapsulating functionality to track the user's progress and update the user related information represented in Learner Profiles.

9. Implementation and application of the proposed framework and architecture. The framework and architecture proposed here were applied and implemented in LOGOS project *Knowledge-on-Demand for Ubiquitous Learning* (IST-4-027451) to support the needs of repurposing of existing multimedia material and the gradual development of pedagogy-driven personalized learning experiences in a static or dynamic way [1, 4, 5, 27].

Moreover, parts of the methodology and solutions proposed in this paper were applied and implemented in the Natural Europe project to support the need of Natural History Museums to make available their cultural digital collections and support their gradual repurposing to develop pedagogy-driven learning experiences in the form of educational pathways based on educational templates encoding instructional strategies to support different learning scenarios [1, 22, 23, 24, 28].

The PhD research is further implemented and applied in a series of papers published under the support of Research project No. DN02/06/15.12.2016 *Concepts and Models for Innovation Ecosystems of Digital Cultural Assets* (2016–2018) financed by the Bulgarian Science Fund and specifically in WP2: "Creating models and tools for improved use, research and delivery of digital cultural resources". The project conducts fundamental research in the areas of computer science, information and communication technology and partly in the humanities and social sciences with the goal of acquiring new knowledge on the fundamental causes of phenomena and observable facts in these areas without any direct commercial application or use.

10. Conclusions. The paper presented a framework for supporting personalized learning services in cultural digital collections/libraries, by a) supporting re-purposing of multimedia digital content/archives to cultural digital objects, learning objects and higher learning units, and b) supporting the construction of pedagogy-driven personalized learning experiences in multimedia digital archives statically or dynamically. Towards this end it defined four models: the domain model, learner model, instructional model and adaptation model. An integrated service-oriented architecture and functional components (including repositories, tools, delivery components, applications and services) were developed based on interoperability standards to support repurposing of existing multimedia digital content to cultural digital objects, learning objects and higher learning units for the construction of pedagogy-driven personalized learning experiences statically or dynamically. The architecture supports interoperability and sharing of cultural digital objects, learning objects and learning experiences with existing eLearning systems and large repositories/aggregators. The methodology and solutions proposed in this paper were applied and implemented in the European research projects LOGOS and Natural Europe.

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