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From Research Resources to Learning Objects: Process Model and Virtualization Experiences

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ABSTRACT

Typically, most research and academic institutions own and archive a great amount of objects and research related resources that have been produced, used and maintained over long periods of time by different types of *domain experts* (e.g. lecturers and researchers). Although the potential educational value of these resources is very high, this potential may largely be underused due to severe accessibility and manipulability constraints. The *virtualization* of these resources, i.e. their representation as reusable digital *learning objects* that can be integrated in an e-learning environment, would allow the full exploitation of all their educational potential. In this paper we describe the process model that we have followed during the virtualization of the objects and research resources owned by two academic museums at the *Complutense* University of Madrid (Spain). In the context of this model we also summarize the main aspects of these experiences in virtualization.

Keywords

Repositories of learning objects, Authoring of domain–specific learning objects, Virtual museums, Virtual campus

Introduction

A research center usually owns and archives a great amount of objects and research related resources whose pedagogical value is unquestionable. Unfortunately, in many cases the scarcity and the value of this material also hinder its use for educational purposes. Two paradigmatic examples are the museums and the archives owned and maintained by many academic and research institutions. The transformation of all these materials into reusable digital learning objects (LOs) (Koper, 2003; Polsani, 2003) that can be integrated and used in an e-learning environment is, in our opinion, a key step to attaining the full exploitation of their educational value. We have confirmed this fact during our experiences with the virtualization of two academic museums at the *Complutense* University of Madrid (Spain): the *Antonio Ballesteros* museum, an academic museum of archaeology and ethnology maintained by the *Department of American History II*, and the *José García Santesmases Computing museum*, an academic museum maintained at the *School of Computer Science*.

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In this paper we present and illustrate the process model used in the two aforementioned virtualization experiences. Our virtualization process model establishes a set of guidelines for the construction of repositories of digital LOs from pre-existing research resources in specialized domains like the two mentioned above. This model, which is based on our previous experiences with a *document-oriented* approach to the development of content-intensive (e.g. educational, hypermedia and knowledge-based) applications, makes it easy for the virtualization of these resources to be carried out by the same experts that use, and in many cases have produced, them. In addition, this virtualization task should suppose a minimum overload in the habitual work of these experts. For this reason, the approach involves a community of *developers* supporting experts in the task of virtualization. Experts and developers collaborate in the definition of an adequate LO model specific to the domain. This model lets developers build a domain-specific application for the authoring and deployment of these LOs. Since this application is especially adapted to the bodies of expertise and to the skills of the experts, the task of virtualization can be dramatically facilitated.

The rest of this paper is organized as follows. We begin by describing the virtualization process model: we present the different products and activities involved in the process, we show the sequencing of these activities, and we also outline the main participants and their responsibilities. Next we describe our virtualization experiences in the domain of the two academic museums aforementioned: we illustrate how the different activities described in the process model take form in each scenario, and we concentrate on the results of the virtualization. We finish the paper with some conclusions and lines of future work. A previous version of the work described in this paper can be found in (Sierra et al. 2005b).

The Virtualization Process Model

The collaboration between specialists in different knowledge areas, in order to be effective, must be adequately ruled. In our opinion, the rules used must emerge from the working experience in each specific domain instead of being adapted from aprioristic universal principles; consequently they must be refined and developed to accommodate the ongoing needs of experts and developers in each domain. The production and maintenance of reusable learning material from pre-existing research resources in specialized domains (e.g. the academic museums) is not an exception. The virtualization process model presented in this section is in accordance with these pragmatic considerations, since it has emerged from our practical experiences at the Complutense University. During these experiences we have recognized the typical scenarios contemplated by our previously mentioned *document-oriented* approach to the development of content-intensive applications (Sierra et al. 2004; Sierra et al. 2005a), and thereby we have adopted a strategy in structuring our virtualization process model similar to the strategy promoted in the *document-oriented* approach. Hence we introduce three different views, as established in Figure 1:

- In the *products and activities* view we include the activities in the approach along with the products produced and consumed by these activities.
- In the *sequencing* view we show how the activities considered are sequenced. Note that in this context the term *sequencing* does not mean the sequencing of the learning activities as it is usually understood in the e-learning domain, but the sequencing of the activities followed by the experts and the computer science technicians when they collaborate in the production and maintenance of the learning materials. Therefore, this view has nothing to do with any e-learning specification. It only reflects a pre-established characteristic of a process model.
- In the *participants and responsibilities* view we outline the participants in the activities along with their responsibilities in these activities.

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In this section we examine the process model from these three different perspectives.

Products and activities

The products and activities contemplated in the virtualization process model are displayed in Figure 1a. As shown in this Figure, the model introduces three different activities (*Domain Analysis*, *Operationalization* and *Virtualization*) and it produces three different kinds of products (a domain-specific LO *model*, a domain-specific *authoring and deployment tool* and the LO *repository* itself). Also notice how the model supposes the existence of a huge body of pre-existing research resources. Next we describe these aspects.

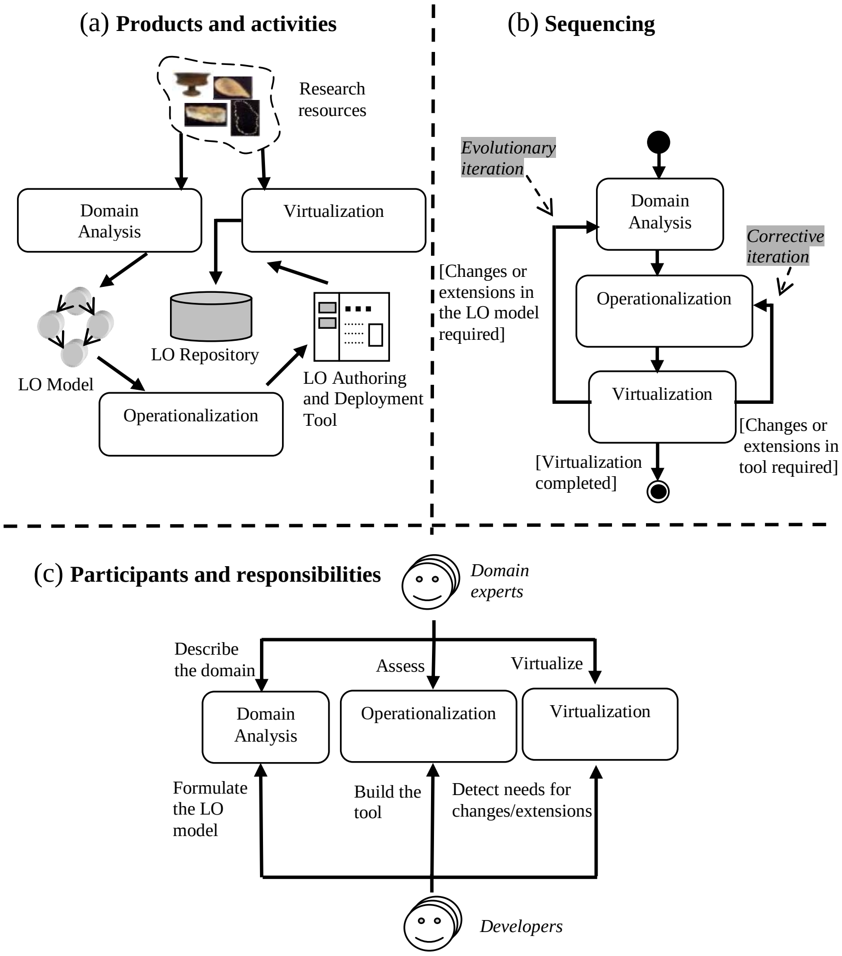

Figure 1. The three views of the virtualization process model

The goal of the *Domain Analysis* activity is the formulation of an *LO model* that makes the educational features of the *research resources* created and manipulated by the experts explicit. This model must be able to integrate all the specific features needed by the experts in a knowledge area to describe and to manipulate the objects and the research goals in that area. Therefore the model for a domain must closely mirror the nature of the actual resources in the domain (e.g. the LO model in the domain of archeology can include resources and features different from the LO model used in natural history, because experts in each domain are interested in different characteristics of the object and have different research objectives). The capability of the model to include all the domain-specific characteristics of the object is critical in order to increase its acceptance and usability by the domain experts. In addition, the model should be conceptually independent of existing LO technologies. While these technologies are very valuable from a developer's point of view, they must not condition domain experts unnecessarily during the characterization process of the LOs in their domains of expertise. On the contrary, this activity could be better based on techniques used in software engineering (Arango, 1989) and knowledge engineering (Studer et al., 1999) for the construction of domain models.

During the *Operationalization* activity a suitable authoring and deployment tool is constructed. This activity is driven by the LO model formulated during the *Domain Analysis* activity. Therefore, the resulting tool will also be domain-specific. This activity can take advantage of existing e-learning technologies. Hence, recommendations and standards like those proposed by IMS Content Packaging (IMS CP, 2004), IMS Learning Design (IMS LD, 2003;Koper & Tatersall, 2005) and ADL Shareable Content Object Reference Model (SCORM) (ADL, 2003) can be adopted in order to promote the interoperability of the resulting tool and the shareability and reusability of the LOs produced. These technologies must be considered implementation mechanisms providing additional functionalities to the tool and as such their potential complexity must be hidden from the domain experts. Thus while IMS CP can be easily adopted to add import and export facilities for LOs to the tool under development, IMS LD and SCORM are notably more complex in nature. Therefore the authoring/deployment tool, being domain-specific (i.e. being oriented to let experts author and deploy LOs in a specific and well-established domain), will only provide navigation facilities through the contents of the learning material organized accordingly to these general-purpose information models. In addition, it can provide an application programming interface to connect with standard editors and players for these recommendations. For this purpose, suitable mappings between the generic and the domain-specific model supported by the domain-specific tool must be defined. These mappings can be actually incorporated to the tool using pluggable facilities of the application programming interface. When mapping a general representation of a LO to a domain-specific one, some features can be loosen, although the information items that enables these features can be preserved in the domain-specific representation as hidden resources in order to make the revival of the original material possible when exported. On the other hand, domain-specific LOs can be represented in general-purpose formats in order to allow its use in external general-purpose authoring and playing environments - e.g. visualization systems for SCORM 2004 as those described in (Roberts et al. 2004).

Finally, during the *Virtualization* activity, the repository of LOs is populated with the virtualizations of the research objects and resources. This virtualization is carried out using the tool produced during the *Operationalization* activity. Nevertheless if import and export standard facilities for LOs are added to the tool, LOs can be exported and edited with external tools and after re-imported to the repository.

Sequencing of the activities

The diagram in Figure 1b shows the sequencing of the activities in the virtualization process model. Instead of proceeding sequentially, performing an exhaustive domain analysis, followed by exhaustive operationalization and virtualization, the three activities are interleaved in time. According to this iterative – incremental conception, the LO model and the associated LO authoring and deployment tool are refined whenever new domain knowledge is acquired during virtualization.

Our process model introduces two types of iterations in the construction of the repositories, which are highlighted in Figure 1b. On one hand there are *corrective* iterations, which are related to the process of updating and fine-tuning the LO authoring and deployment tool to accommodate it to the needs of the experts (e.g. by introducing an enhanced interaction style in its user interface). On the other hand, the model also contemplates *evolutionary* iterations, which are related to the evolution of the LO model to capture new research or educational features of the virtualized resources (e.g. by considering new kinds of attributes for the LOs). Both types of iterations can be started during the *Virtualization* activity in response to the specific needs manifested by the domain experts.

During our experiences with the approach we have realized that continuous maintenance and evolution of the LO model and their associated tools are mandatory to better accommodate them to the desires and changing expressive needs of the experts. This obligation supposes a heavy interaction between the experts and the developers of the applications, which can decrease overall productivity. To manage this interaction we are studying the application of the specific techniques proposed by our document-oriented approach for dealing with the intrinsic evolutionary nature of content-intensive applications (Sierra et al. 2005c).

Participants and their responsibilities in the activities

Domain experts and developers are the two main participants involved on the construction of LO repositories, as mentioned before. The different responsibilities that they have in the model's three activities are depicted in Figure 1c. Next we detail these responsibilities.

During the *Domain Analysis* activity, the main role of developers is to formulate the LO model for the objects and resources managed by the domain experts. In turn, domain experts must describe these resources to the developers, how they are used and how they are interrelated, letting developers perform an adequate conceptualization. The acceptability and usability of the resulting LO model will strongly depend on the participation of domain experts, because they know the actual resources, they can describe these resources to the developers, and they can help them in the elicitation of the possible educational uses of this material.

During the *Operationalization* activity, the main responsibility is for the developers. They must construct the LO authoring and deployment tool. During its construction, they are driven by the LO model and they can also be assessed by the domain experts regarding different aspects not contemplated in the model (e.g. presentation and edition styles).

Finally, during the *virtualization* activity, domain experts use the LO authoring and deployment tool to populate the LO repository. In this activity developers can react to the needs manifested by the experts and can start new corrective and/or evolutionary iterations when required.

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Experiences in the Domain of the Academic Museums

We have successfully applied the principles of virtualization explained in the previous section during the virtualization of two different museums at *Complutense* University of Madrid, as mentioned in the introduction: the museum of archaeological and ethnographical material maintained at the Department of American History II (the *Antonio Ballesteros museum*) and the museum of computing at the School of Computer Science (the *José García Santesmases Computing museum*). Using these experiences we illustrate the analysis performed in these domains and we introduce the LO model formulated. Next we briefly outline the operationalization and the architecture of the authoring and deployment tools produced. Finally we detail our working experiences during virtualization.

Domain analysis: virtual objects

Academic museums contain collections of *real* objects that can be directly chosen as the most suitable candidates for conversion into LOs. In these scenarios it is natural to distinguish between such real objects and their virtual representations. These virtual representations will be called *virtual objects* (VOs) because they come from the virtualization of real objects initially with educational purposes (Figure 2a). The VO model was formerly proposed in (Fernández-Valmayor et al. 2003) in relation with the archaeology and ethnology museum but it has also been used in the computing museum, although with different specific features (Navarro et al. 2005).

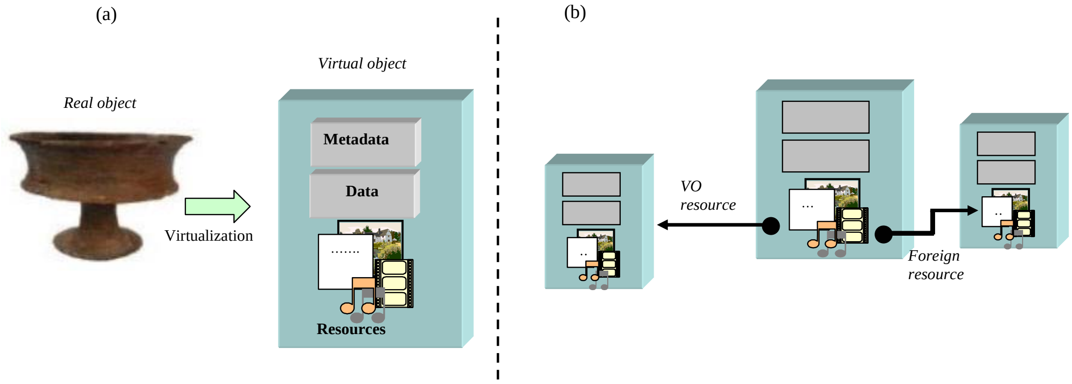

Figure 2. (a) Real and virtual objects; (b) Virtual objects can be related using foreign and reference resources.

In Figure 2a the structure of a VO is outlined. That way a VO is characterized by a set of *data*, a set of *metadata*, and a set of *resources*:

- The *data* in a VO represent all the features of the real object that are considered useful for its scientific study. Examples of this kind of data are the *dimensions* and the result of the *chemical analysis* of a piece of pottery of the archaeology museum, or the *model* and the *components* of a computer of the computing museum.
- The *metadata* are the information used to describe and classify the VO from a pedagogical point of view. Examples of metadata are the *name* of the VO's author, its *version number* or its *classification*. The

different features covered by metadata are chosen from existing exhaustive metadata schemas like the IEEE LTSC Learning Object Metadata (LOM) (LOM, 2002).
- The *resources* are all the other informational items associated with the VO. These are further classified in *own*, *foreign* and *VO* resources. The *own resources* of a VO are the multimedia archives resulting from the virtualization of the real objects (e.g. a set of photographs of a pottery vessel or a video showing the operation of a computer). The *foreign resources* are references to resources belonging to another VO but related to the first one (e.g. documents describing different aspects of the culture that manufactured the pottery vessel, or those related to the research and design process of a computer model). Finally, *VO resources* are references to other VOs in the repository that are related in some way to the first one (e.g. a VO for another piece discovered at the same excavation as the vessel, or a set of VOs for the different components of the computer).

Foreign and VO resources allow the establishment of basic relationships between different VOs (Figure 2b). Indeed this mechanism can be used to build new VOs based on existing ones. These resulting composite VOs may, or may not, correspond to real objects in the museum. In this latter case they usually represent new constructed knowledge and/or new educational facilitators that arise during the virtualization process (e.g. thematic guided tours based on the objects owned by the museum about a cultural or technical subject).

Although the real objects of both museums are very different in nature, the VO model has proved to be flexible enough to deal with the domain-specific data in each knowledge area. Indeed:
- Although the set of data needed to describe a computer prototype is very different from the set of data needed to describe a cultural artifact, in both cases researchers can choose the set of attribute-value pairs needed to describe the set of features in which they are interested.
- In the same way, resources associated with the VO can gather all the digital archives that result from the virtualization process of a computer prototype or from the virtualization process of an archaeological object.
- Moreover, through foreign and VO resources, the relation of a computer prototype with its components and with the research work, documents and tests that preceded its construction can be expressed in a similar manner to the relation between a pottery vessel and the other artifacts that were dug at the same archaeological site. In addition, when dealing with cultural artifacts, foreign resources will mainly be research documents describing different aspects of the culture that produced them or, alternatively, the VO representing all the field work involved in a specific archaeological project. Similar relationships also exist between computers and digital devices and their manufacturing processes.

It is important to point out that although VOs and their associated resources can resemble SCOs and assets in SCORM still there are important differences between them. In SCORM, SCOs cannot refer to assets in other SCOs neither other SCOs themselves, while the possibility of these relations is a main feature for VOs. Conceptually, a VO gathers all the information relevant to a physical or conceptual object. Its associated resources can be as simple as SCOs assets, but also can be complex structures describing a learning process and the workflow of the learning activities in which this VO can be implicated.

Operationalization: web-based authoring and deployment tools for virtual objects

The VO model has led us to develop simple web-based authoring and deployment tools for the two aforementioned museums (Figure 3). Basically these tools enable authors to create VOs, upload their resources and to establish their relations with other VOs and/or their resources. Users can navigate the repository of VOs and their associated resources, thus the complexity of the navigation depends of the navigational structure of the resource. The tool for the museum of archaeology (Figure 3a) is called *Chasqui*. The word *chasqui* means *messenger* in *Quechua*, the language spoken in the *Inca* Empire. *Chasqui* has gone through a strong evolution, as described in (Navarro et al. 2005). In the initial version of *Chasqui* (Chasqui Web Site, 2005), VOs were directly mapped onto its database representations. While the resulting application enabled users to author learning objects using domain-specific authoring tools, we found serious difficulties regarding portability and interoperability with other systems and authoring tools. For this purpose we have adopted a more sophisticated architecture, based on well-known interoperability standards. The resulting version can be visited in its testing site (Chasqui2 Web Site, 2005), and it is scheduled to be in production in the first quarter of 2006. The architecture of this new version of *Chasqui* has also been reused in the development of the tool for the computing museum (Figure 3b). This tool is called MIGS (MIGS Web Site, 2005), the acronym for the name of the museum in Spanish.

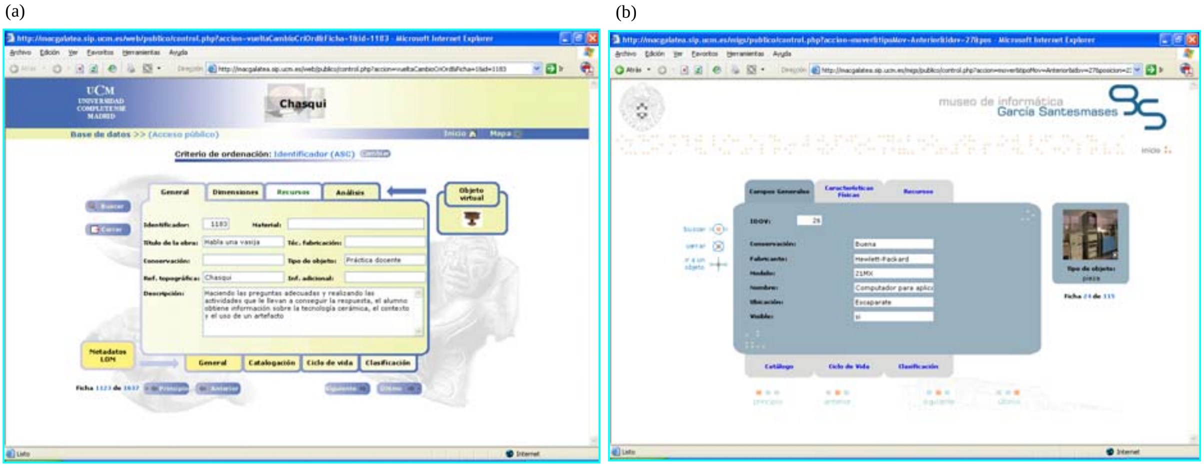

Figure 3. Snapshots for (a) Chasqui; (b) MIGS

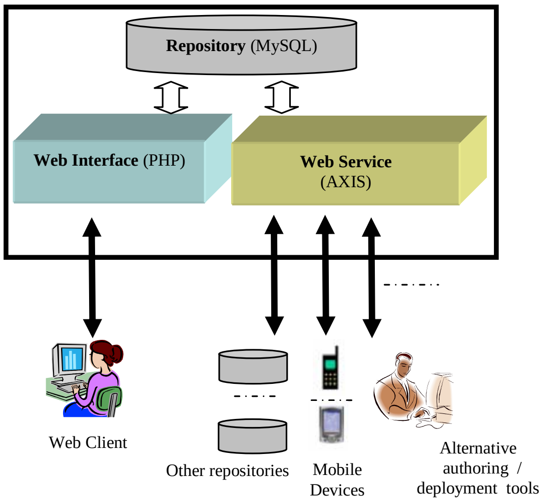

Figure 4. Architecture of the Web Based Authoring and Deployment Tools

The final architecture proposed during Operationalization is depicted in Figure 4. According to this architecture, the repository of VOs continues to be supported by a relational database. The tools include pre-established web interfaces tailored to the museums being virtualized. In addition, these tools also include programmatic interfaces accessible via *web services* (Cerami, 2002). Web services facilitate the interoperation with other repositories, enable different accessing mechanisms (e.g. mobile devices) and permit the use of external tools with alternative and more powerful interaction styles (e.g. IMS LD and SCORM editors and players). As suggested in Figure 4, this architecture is entirely implemented using open source technologies.

To enable interoperability, the tools incorporate import and export facilities of VOs in accordance with the IMS CP specification. This way, VOs can be packaged according to this specification and can be exported to other IMS-aware Learning Management Systems able to conduct a more elaborated learning process. Direct importation is also possible between repositories associated with museums sharing a common VO model. More complex importation processes can also be automatically achieved by connecting the appropriate adapters to the web service interface. Indeed, this interface is the point where mappings between general-purpose representation formats (e.g. SCORM or IMS LD compliant learning materials) and the VO model can be readily incorporated. By incorporating to it the appropriate importation and exportation mappings, many current and future learning application profiles could be readily supported, maybe with slight evolutions of the current VO model.

Virtualization

The tools described in the previous section are being used in the virtualization of the two aforementioned museums. While the virtualization of the computing museum is in its initial stages (115 VOs included on December 2005), the virtualization of the archaeology museum is in an advanced state. Indeed, *Chasqui* has been in production since the year 2003 and has therefore had enough time to prove the usefulness of the iterative – incremental conception of the aforementioned virtualization process. Currently, the resulting virtual museum contains more than 1500 VOs and the virtualization process continues to be active. Beyond its capabilities for creating simple collections of VOs, the *Chasqui* tool, being in a more advanced virtualization state than MIGS, has proven very valuable in several research and pedagogically related activities oriented to students with very different backgrounds. In particular, as it will be detailed in the next sections, *Chasqui* has evolved from its original purpose to be a very valuable tool for supporting the active learning of the research process by junior students and of its refinement by senior and PhD. students. In addition, Chasqui has also proven very valuable as a basic tool for the just-in-time publishing of research resources. Next we summarize some of these experiences.

Virtualization and dissemination of pre-existing materials

The primary use of *Chasqui* and MIGS was to let students and the general public learn about the objects found or collected during an archaeological or ethnological field season, or to learn about the computing devices built at the university by pioneering professors. For this purpose, in the initial virtualization iterations the repositories of both museums were populated with such elementary VOs.

The publishing of this kind of stored and archived resources makes tools like *Chasqui* and MIGS very valuable artefacts for disseminating pioneering work and the patrimony of the academic museums among the general public. This way, by exhibiting many pieces of hardware, like those shown in Figure 5a (MIGS VO number 2), as VOs, the computing museum has gained considerable popularity among students. The museum itself is discovered in Internet, and instructors and students can use MIGS for documentation prior to visiting the real museum at the *Computer Science School*. As another recent example, 23 pieces in the archives of the museum of archaeology were located using *Chasqui* and selected for the exposition *Pueblos Amazónicos: Un Viaje a otras Estéticas y Cosmovisiones* (*Amazon Cultures: A Journey to other Aesthetics and Cosmovisions*) organized for the general public by the *Museum of Science of Castilla-La Mancha* (Cuenca, Spain, 1-30 Junio 2005).

(a) (b)

Figure 5. (a) a VO in MIGS; (b) Unpublished pottery vessel neck from *Proyecto Esmeraldas* that was re-recovered during the virtualization process

Another interesting experience, this time related to *Chasqui*, has been its use for reviving unpublished archaeological material for research and pedagogical purposes (Figure 5b). This is indeed the case with several Archaeological and Ethnological projects already finished at the Department of American History II: *Chinchero*, *Incapirca* and *Esmeraldas*.

Work Assignments for Undergraduate Students

In *Chasqui* the research materials collected at different archaeological sites have been used to design work assignments for undergraduate students. The flexibility of the VO model lets teachers conceive these assignments as a new composite VOs.

In Figure 6a we show some snapshots corresponding to one of these assignments for an undergraduate introductory course on the *Andean archaeology area* (Chasqui VO number 1183). As a deployment tool, *Chasqui* can be combined with typical Learning Management Systems (LMS) as has been the case with these work assignments that have been made accessible to students using the virtual campus of the Complutense University, currently supported by the WebCT platform (Rehberg et al. 2004). This lets us take advantage of the communication and learning management features of a typical LMS (e.g. discussion forums and management student facilities) in conjunction with the other features of *Chasqui*.

Involving Advanced Undergraduate and Graduate Students in the Virtualization Process

We have also used *Chasqui* to involve advanced undergraduate and graduate students in the construction of new composite VOs, therefore promoting active learning among these students. Again the flexibility of the VO model

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enables students to construct new VOs by referencing pre-existing foreign resources and also pre-existing VOs. In addition, students can also collaborate in the elaboration of new original resources.

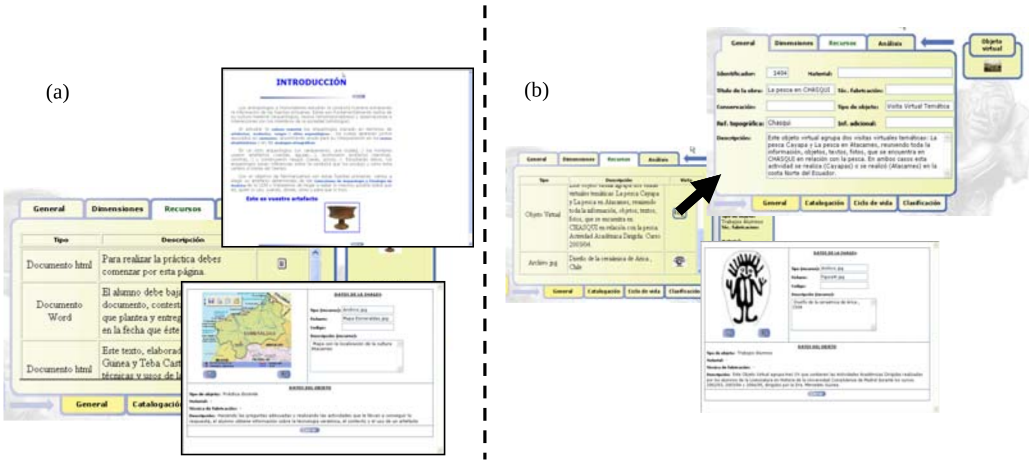

Figure 6. Snapshots of (a) a work assignment for undergraduate students, (b) a VO produced by graduate students

The snapshots shown in Figure 6b correspond to a VO produced by a group of graduate students enrolled in a course about *Aztec Culture* (Chasqui VO number 1683). In addition to the pedagogical benefits of their active involvement, the work performed by the students is made available to other users and it can be used as support material in future editions of the course. As with the undergraduate-level experiences, we have realized the advantages of integrating the domain-specific virtualization activity with the generic facilities provided by a general-purpose LMS, like WebCT. In this case the groups of students can share a server file to interchange the digital materials needed for the virtualization, as well as a private newsgroup and a personal e-mail for communication purposes.

Involving PhD. Students in the Virtualization Process

We have used *Chasqui* to implement a new pedagogical strategy in a PhD. course on *New Information Technologies in Andean Archaeology*. Students enrolled in this course are integrated as active members in our research group. This is an interdisciplinary group formed by both archaeologists and computer scientists. One of the main research interests of the Computer Science branch of the group is the formulation of domain-specific descriptive markup languages (Goldfarb, 1981;Coombs et al. 1987) to structure documents of different knowledge areas for multiple purposes. Our interest in the use of makup languages is directly related with the aforementioned document-oriented approach for the development of content-intensive applications. Therefore, we propose that PhD. students define their own markup languages to structure the documents that they produce with different purposes: research, dissemination or education.

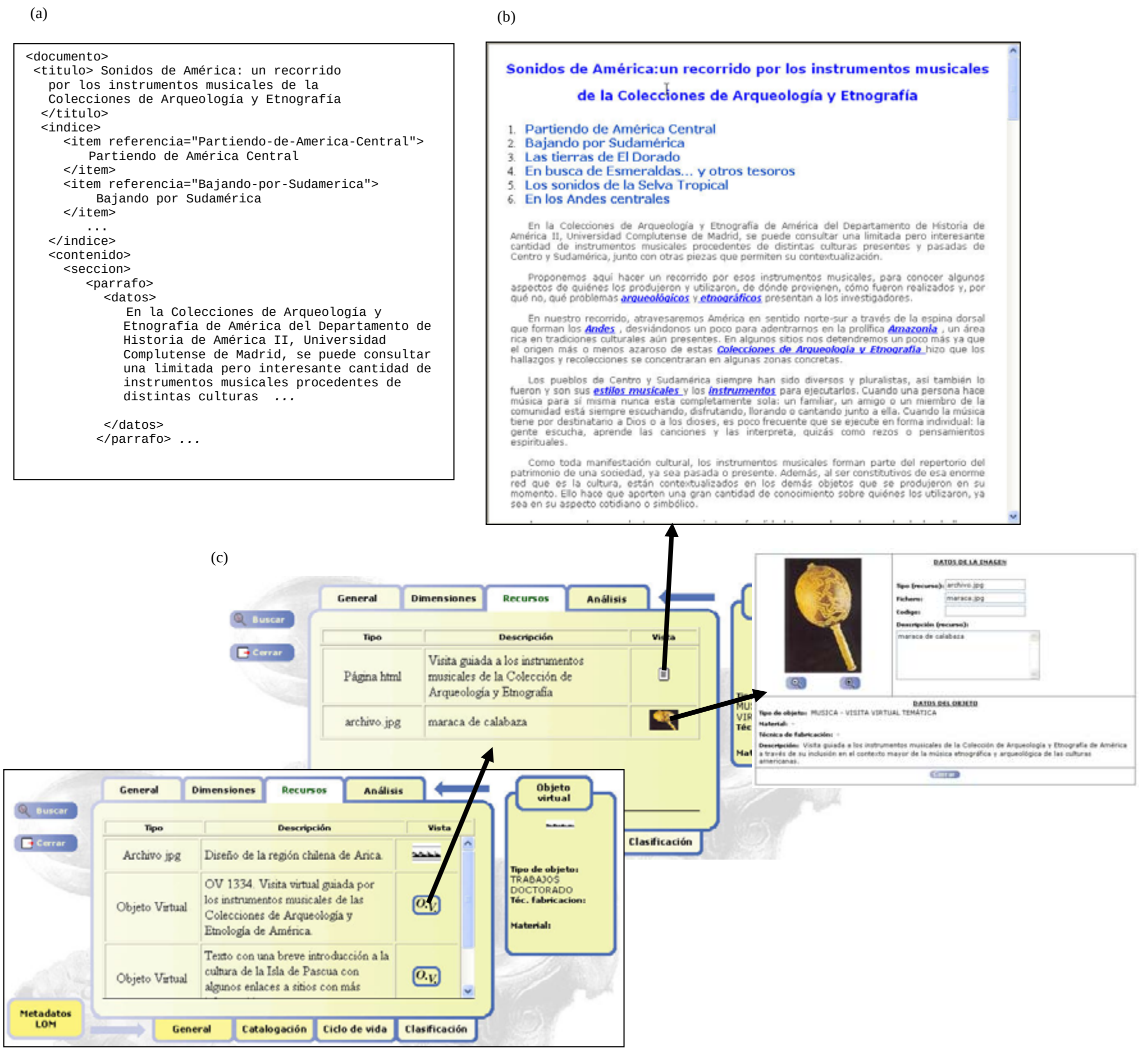

Figure 7. (a) An archeological marked document; (b) presentation generated from (a); (c) VO resource with the presentation in (b).

The languages created by the students (with the help of their teacher) are conceived as descriptive markup languages defined using XML (XML, 2004). A typical workflow of the process is as follows:

- The teacher assigns research papers about different subjects to each student.
- Then the students must synthesise the main ideas in the papers they have studied and, in a following session, discuss their syntheses with the rest of the group.
- When the students have enough knowledge about the subject, they must create composite VOs, gathering and structuring as much information as possible regarding this subject. Among these resources, they must include documents describing the results of their research. These documents, which are the most common in

the domain, can be classified by: (i) their final purpose (site reports, essay, review, research or dissemination papers), (ii) their primary sources (artefacts, monuments, site plans or collections), or (iii) by the targeted audience (public or academic).

- In the next stage, each of the documents elaborated is analyzed to identify its structural elements, its hierarchical organization and the labels and the attributes to be used to make all the information that they convey explicit.
- The documents are marked up and a first attempt to abstract the type of these documents as XML document grammars is carried out with the help of *Chasqui*'s developer community. Note that these document grammars define new domain-specific descriptive markup languages used for authoring purposes. Therefore they do not should be confused with extensions to the XML bindings for the information models proposed by the different e-learning specifications. These document grammars can be also used and refined by subsequent groups of students. Therefore, these document grammars are subjected to a continuous evolution. In order to manage this evolution, developers can use suitable XML schema technologies (Lee & Chu, 2000) as well as the techniques for the incremental definition of domain-specific descriptive markup languages described in (Sierra et al. 2005c).
- Finally, the documental resources associated with the composite VOs already created are automatically generated from the marked documents without need, for the students, of further manual processing. For this purpose, they also get support from the developer community. This community produces suitable processors for the domain-specific descriptive markup languages defined by the students. For this purpose they can use standard XML processing technologies (Birbeck et al. 2001) or the more advanced solutions oriented to facilitate the incremental construction of such processors described in (Sierra et al. 2005c).

In Figure 7a we show part of a document marked with a domain-specific markup language developed by a group of PhD. students during the course's edition of 2004-2005. Note again that this document is used only during authoring. Indeed, the resource finally integrated in the VO is the result of transforming it to HTML - in this particular case an XSLT style sheet (XSLT, 2004) was used to carry out the transformation. Therefore, the markup used here is domain-specific and has nothing to do with the tags used in the XML bindings for the different information models proposed by the e-learning community (e.g. markup for representing IMS CP manifests). In Figure 7b we show the resource (an HTML page) generated from this document. In Figure 7c we show some snapshots of the Chasqui VO where the resource is finally integrated (Chasqui VO 1430).

Just-In-Time Diffusion of the Research Results

Domain-specific authoring tools like *Chasqui* allow, for researchers, the continuous and just-in-time update of the VOs. The only requirement is an internet connection, since the usability of the tool makes the presence of developers unnecessary. That way, research results and field work reports can be published as they are obtained, letting the interested researchers and students access these results without waiting for their diffusion over more conventional publishing channels (e.g. specialized conferences and journals).

In Figure 8 we show some snapshots of a VO (Chasqui VO number 1743) related to the field work and the preliminary reports for the Project *Manabí Central*, which is being carried out by an international research consortium at *Chirije* and *San Jacinto de Japoto*, on the Ecuadorian Coast (Bouchard, 2004). Another related use of *Chasqui* is the organization as VOs of the content and development of other research activities, like symposiums (see Chasqui VO number 1431 in the *Chasqui* web site).

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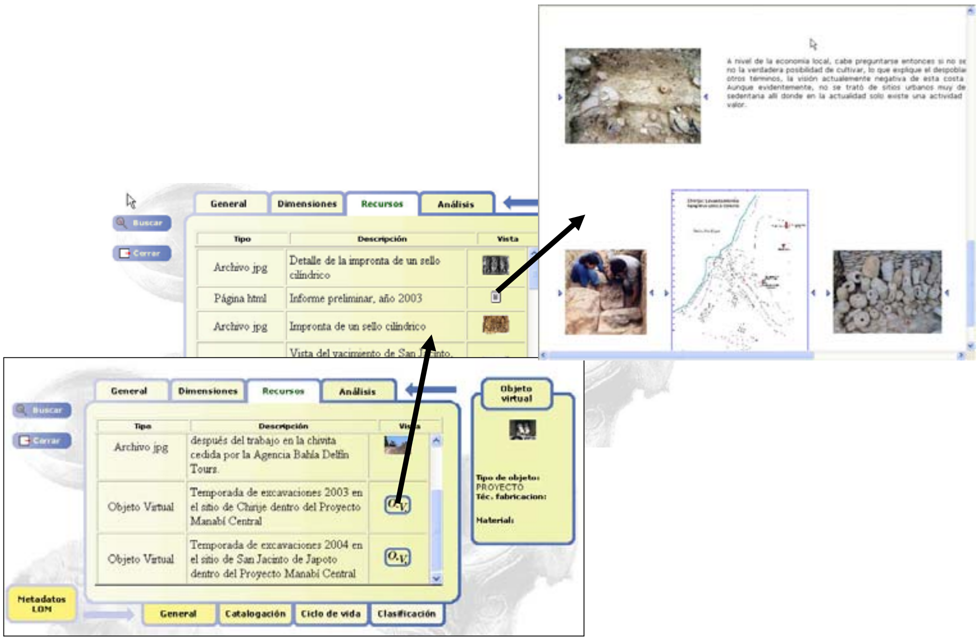

Figure 8. VO with the preliminary reports of the Project *Manabí Central*

Conclusions and Future Work

The virtualization process model described in this paper lets domain experts create repositories of LOs in a very dynamic way. For this purpose domain-specific LO models are formulated and supporting authoring and deployment tools based on these models are developed. These tools are used by the experts to produce the repositories. We have realized that the approach is very valuable for exploiting the educational potential of otherwise underused and/or access-limited research materials. We have also realized that the approach allows the creation of new knowledge as reusable composite LOs for many different pedagogical and research purposes. But perhaps the most relevant and in some way unexpected result of our work, from an e-learning perspective, has been how teachers and students are using the system. This way, they are finding that *Chasqui* is a very useful tool for supporting active and collaborative learning, involving both student-student and teacher-student relations as has been shown in the virtualization experiences described in this paper.

Currently we are finishing the first stage in the virtualization of the computing museum, and we are also starting several virtualization experiences regarding the virtual campus of the *Complutense* University of Madrid. We are also working on another evolution of the VO concept, by extending VOs with *scripts* documenting the sequencing of their resources. These scripts will be implemented by using the IMS Learning Design Specification (IMS LD, 2003;Koper & Tatersall, 2005). As future work we are planning to undertake the virtualization of other museums at this university in order to refine the concept of VO. We are also planning to further use our document-oriented approach (Sierra et al. 2004; Sierra et al. 2005a) to improve the maintenance of LO domain-specific authoring tools by enabling their full documental description.

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