LEARNING MATERIALS: TOWARDS THE
ESTABLISHMENT OF GUIDELINES FOR
DOMAIN MODELING

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Abstract
Domain modeling plays a fundamental role in the educational process, especially regarding to the development of learning materials. Despite its relevance, there are few approaches specifically designed for the educational content modeling task. Moreover, there is not a consensus on the features that a domain model should present and on the mechanisms that the underlying modeling approach should provide in order to facilitate the development of learning materials. In this work, we investigate the characteristics of a domain modeling approach as well as the possible types of information it should handle for establishing an initial set of guidelines to model educational contents. In addition, three approaches to the development of educational hypermedia applications are analyzed according to the proposed guidelines.

Keywords: Learning Materials, Conceptual Modeling, Instructional Modeling, Didactic Modeling, Teaching and Learning Processes.
1. INTRODUCTION

Several initiatives involving the use of new technologies and computational resources in order to ease the educational process have been investigated. It is the case of learning environments, based on networking and WWW technologies, which have been developed to support teaching and learning activities, such as contents authoring and delivery, students evaluation, and collaborative work [Goldberg et al., 1996, Lucena et al., 1998, Menasce, 1998, Adriano et al., 1999, Abowd, 1999, Guzdial, 1999]. However, it is important to think whether the research efforts conducted lead to improving or creating new learning situations for students and teachers, or if they are just bringing the same problems and difficulties found in traditional teaching and learning processes to another scenario [Rodríguez-Artacho et al., 1999].

The development of richer and more interactive learning materials capable of motivating the students and effectively contributing for their knowledge construction process plays a fundamental role in the educational context. For learning materials we understand the printed materials, the electronic materials, or a combination of them. In this work, these terms will not be differentiated, unless necessary.

Learning materials construction is a complex task, involving a series of both pedagogical and developmental issues: to define the learning purposes; to determine and to structure the conceptual and instructional objects that will compose the educational content; to establish a didactic approach to be used; and to define how the material should be presented to the students, for instance.

Domain modeling plays a significative role in the construction process of learning materials. This activity helps the author to determine the relevant parts of the subject knowledge domain and also provides a systematic way to structure the concepts and their relationships. Despite its relevance, few approaches are specifically designed for modeling educational contents. Consider, for instance, the development of educational hypermedia applications. The models used for designing generic hyperdocuments, such as HDM [Garzotto et al., 1993], RMM [Isakowitz et al., 1995], and OOHDM [Schwabe and Rossi, 1995], can be used for dealing with the navigational and presentation aspects of the educational applications construction, but are not suitable for completely modeling these types of applications since they neither focus on the domain concepts nor deal with the instructional and didactic issues.

Concerning the learning environments, although they support the storage and retrieval of educational contents, no mechanism for modeling
the related knowledge domain is provided. The educational contents modeling is left in charge of the author, without any systematization.

Two related questions can be posed in the context of domain modeling task: “What features should we consider when developing a domain model for a given educational content?” and “What mechanisms should the underlying domain modeling approach provide in order to facilitate the development of learning materials?”.

This work aims at identifying some characteristics that a domain modeling approach should present as well as the kind of information it should handle and, based on them, to establish an initial set of guidelines to model educational contents. As a preliminary study, three approaches for the development of educational hypermedia applications are analyzed according to the proposed guidelines. It is important to notice that the set of guidelines here defined consists in a first step to the establishment of requirements for the comparison and evaluation of domain modeling approaches.

The remainder of this paper is organized as follows. In Section 2, an architecture for the development of learning materials is presented. Section 3 discuss some specific aspects related to domain modeling and defines a preliminary set of guidelines for modeling educational contents. Based on the proposed guidelines, three approaches for the development of educational hypermedia applications are briefly analyzed in Section 4. Finally, in Section 5, our conclusions and further work are presented.

2. AN ARCHITECTURE FOR THE DEVELOPMENT OF LEARNING MATERIALS

In this section we present an architecture, named LMD – Learning Material Development – architecture, which aims at aggregating in a unique proposal the main activities that should be performed when developing a given learning material. The LMD architecture is illustrated in Figure 1 and comprises the traditional phases of a system development process: planning, modeling, design, implementation, testing, and maintenance (evolution).

In the planning phase, we should delimit the scope of the learning material, in terms of the knowledge domain as a whole. The learning purposes of the material, the audience of the course and the pedagogic approach to be adopted are examples of aspects that should be specified in this phase. Cost and schedule may also be addressed.

The domain modeling phase, which is the focus of our work, is concerned with the structure and organization of the educational content.
It can be divided in a series of sub-phases – conceptual modeling, instructional modeling, and didactic modeling –, each one dealing with different aspects of the modeling activity. These sub-phases are discussed in more details in the next section. Formalisms, such as ontologies [Guarino, 1997], can also be applied and incorporated in the domain modeling phase in order to formally define and represent the concepts and relationships associated with the knowledge domain.

The design phase deals with the presentation of the material to the learners. In the case of electronic materials, the navigational aspects must also be considered in this phase. Furthermore, structured documents can be generated based on the models previously developed. The mapping from a given model to a structured document can be done by using a mark-up language, such as XML (eXtensible Mark-up Language) or SGML (Standard Generalized Mark-up Language).

In the implementation phase, we are interested on obtaining the “concrete” learning material. For instance, considering an educational hypermedia application, a web-based learning material can be automatically generated from the structured documents by means of a compiler.

The testing phase involves two perspectives: to validate the material in terms of the learning objectives specified in the planning phase, and to verify its correctness. Notice that the testing phase occurs in parallel with the other phases of the development process.

The maintenance (evolution) phase focus on the necessary changes for correcting and preventing eventual problems and errors in the developed material. Also, it deals with the evolutionary aspect of the information related to the knowledge domain, which often requires updates in the material.
A data dictionary should be constructed in order to support documentation and static analysis of the learning material through the development phases. The concepts of the knowledge domain and their relationships are described in the domain dictionary, a relevant piece of the data dictionary, developed in the domain modeling phase.

3. DOMAIN MODELING: A PRELIMINARY SET OF GUIDELINES

Learning materials usually include a content matter structured description together with questions, examples, further explanations, problems to be solved, suggestions for further study, and so on [Rodríguez-Artacho et al., 1999]. In this sense, the domain modeling phase establishes a set of models, based on three different perspectives: 1) the conceptual perspective refers to the content matter description; 2) the instructional perspective deals with the instructional elements used to perform the teaching and learning processes; and 3) the didactic perspective aims at relating the conceptual and instructional elements. Although each perspective addresses a particular aspect in the learning material development, they are intrinsically related and should be put together, in an integrated way.

Next we discuss the domain modeling phase, presenting an initial set of guidelines for modeling educational contents. The guidelines are based on conceptual, instructional and didactic perspectives and impose that specific notations be incorporated to a domain modeling approach.

3.1 Conceptual Modeling

The conceptual model consists in a high-level description about the knowledge domain, subject of learning. The domain elements are characterized in terms of concepts, which can be defined in terms of other relevant concepts and from the relationships held among them.

The relationships can be divided into two classes [Mayorga et al., 1999]: structural and domain-specific ones. Structural relationships allow setting up taxonomies among concepts, permitting to make inferences about the knowledge domain. They represent a generic category of relationships that can be applied on any knowledge domain and should be predefined by the domain modeling approach. The relations type-of and part-of are examples of structural relationships.

Domain-specific relationships have their meaning associated to a particular subject, carrying their own semantics. In other words, they represent the specific relations, whose interpretation depends on the do-
main (or application) subject of modeling. These relationships are user-defined.

- **Guidelines for the Conceptual Modeling**

  According to the Ausubel’s cognitive psychology [Ausubel et al., 1978], the meaningful learning takes place by incorporating new concepts and propositions into the learner’s previous knowledge framework. In this sense, the establishment of an hierarchical structure of the knowledge domain, in which the more inclusive and general concepts are identified and represented prior to the more specific and less general ones, can enhance the meaningful learning process and promote the integration of new knowledge with the learner’s preexisting one.

  The hierarchical structure of the knowledge domain implies on two related perspectives. On the one hand, it establishes concept taxonomies, which can be represented by means of structural relationships in the conceptual model. On the other hand, it deals with the idea of conceptual modules, where a group of concepts instead the concept itself should be considered. General modules should be presented prior to specific ones. Each module contains only the concepts strictly related, characterizing cohesive units of study. In fact, if the number of relevant concepts associated with the knowledge domain is high, their representation in a unique space may compromise the legibility of the model and affect the quality of the learning material under development. In this sense, the conceptual model should provide mechanisms for structuring large bodies of knowledge into conceptual modules. A well-defined semantic for representing the relationships between concepts of different modules is also required.

  The idea of concepts composition, which indicates that a concept can be defined and explained in terms of other ones, can be used as a mechanism to facilitate the understanding of the knowledge domain and, for this reason, should also be considered in the conceptual modeling.

  Finally, as stated before, the relationships in the conceptual model are characterized in structural (predefined) and domain-specific (user-defined) ones. Since the conceptual model is a high-level description about the domain, it must be flexible enough to support both classes of relationships among the concepts.

  The main points here discussed lead us to the establishment of four guidelines, specific for the conceptual modeling context:

  - Represent concepts taxonomy;
  - Provide mechanisms for domain modularization;
Represent concepts composition; and

Represent domain-specific relationships.

3.2 Instructional Modeling

To better understand and assimilate a given knowledge domain, a diversity of information can be associated with its related concepts, in different ways. As stated by Mayorga et al. [Mayorga et al., 1999], the actual learning of the topics represented in the conceptual model requires a range of instructional objects, which correspond to the elements used for illustrating and practising the concepts, and for evaluating the student’s knowledge.

Three kinds of instructional objects can be identified [Mayorga et al., 1999]: explanatory, exploratory and evaluative. The explanatory objects deal with the complementary information used for explaining a given topic. They can be associated to a conceptual object or to any other instructional object. Descriptions, examples, hints, suggestions of study, and explanations are kinds of explanatory objects. Furthermore, they can play a number of different roles depending on their instructional purpose. An example, for instance, can be associated with a given object in two distinct perspectives: to motivate the study of the object, or to illustrate its use.

The exploratory objects allow the student to navigate through the knowledge domain and to practise with the related concepts that he is supposed to learn. The proposition of a given problem, which enunciates an exercise to be solved and indicates a reference material for its solution, is a type of exploratory object.

The evaluative objects allow the student to assess his proficiency on the knowledge domain. A multiple-choice question, representing a small problem with a number of possible answers, is an example of evaluative object. The proposition of a given problem, in which the answer is not provided to the student in advance, can be considered an evaluative object as well.

Notice that in the instructional model we are not interested on how the information will be associated, but on what kind of information we can use to develop significative and motivating learning material.

Guidelines for the Instructional Modeling

Instructional elements should be explicitly represented in the instructional model in terms of descriptions, examples, exercises, comments, and all other kinds of information that can be associated with a given
concept in order to make easier its understanding and assimilation by the learners.

The relevant information that should be represented in the instructional model can be determined through the specification and refinement of the internal structure of each concept related to the knowledge domain, subject of modeling. In fact, to structure the concepts in terms of smaller pieces of information (internal structure) corresponds to the establishment of instructional elements. In this sense, we establish the following guideline, concerning to the instructional modeling:

- Specify the internal structure of concepts.

3.3 Didactic Modeling

The didactic model relates the conceptual and instructional models, holding the information about the didactic usage of their objects. It allows adding extra information to the conceptual and instructional objects, which can be used to adapt and reuse the educational content in a variety of situations and for a range of didactic purposes and learning objectives.

Guidelines for the Didactic Modeling

The most basic way for representing the didactic dependencies between the concepts is by defining prerequisites among them. If a concept is a prerequisite of another one, the former must be studied before the latter, establishing a sequence of presentation to them. Notice that more than one sequence of presentation can be established for the same group of concepts, according to the learning objectives of the course, the teacher’s didactic purposes and the learner’s profile.

In addition to the precedence idea, some expressions such as illustrate (linking an example and a concept), describe (linking a description to a concept or a problem) and exercise (linking an exploratory object to any conceptual one) can also be used for representing didactic relations between the concepts.

Based on these aspects, we establish two guidelines in the context of didactic modeling:

- Represent concepts precedence; and
- Represent didactic relationships.

It is important to notice that, in the present work, we are not dealing with how to proceed the transition from the objects of the “real” world to
the objects of the domain model, as occurs, for instance, in the Object-Oriented and Entity-Relationship models. In fact, the abstraction of the reality is a relevant issue in the scope of modeling activity and shall be investigated in the next step of our work.

4. APPROACHES FOR EDUCATIONAL HYPERDOCUMENTS DEVELOPMENT: A BRIEF ANALYSIS

In this section we summarize the analysis of three approaches to the development of educational hypermedia applications: Daphne [Kawasaki and Fernandes, 1996], EHDM [Pansanato and Nunes, 1999] and MAPHE [Pimentel, 1997].

In short, Daphne is based on the concept mapping theory [Novak and Gowin, 1984, Novak, 1990], on the information mapping technique [Horn, 1989], and on the HDM model [Garzotto et al., 1993]. EHDM is based on the concept mapping theory and on the Michener’s work [Michener, 1978]. MAPHE incorporates to the concept mapping theory some usual relationships of the object-oriented modeling [Rumbaugh et al., 1991].

Table 1 synthesizes the main features of each approach, analyzed according to the guidelines proposed in Section 3.

<table>
<thead>
<tr>
<th>Domain Modeling Perspective</th>
<th>Daphne</th>
<th>EHDM</th>
<th>MAPHE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conceptual</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concepts Taxonomy</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Domain Modularization</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Concepts Composition</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Domain-Specific Relationships</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Instructional</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Structure of Concepts</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Didactic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concepts Precedence</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Didactic Relationships</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

From Table 1 we can observe that each one of the analyzed approaches emphasizes a specific perspective of the domain modeling task. The conceptual aspects, for instance, are emphasized in Daphne and MAPHE approaches; EHDM just provides mechanisms to support the domain
modularization. The instructional issues are addressed by Daphne and EHDM, while MAPHE does not provide specific mechanisms for dealing with them. The didactic aspects are considered in all approaches by means of the concepts precedence.

In fact, depending on the knowledge domain and on the learning objectives of the course, a given approach can be considered more adequate for modeling the content of the learning material.

For sake of illustration, next we describe in more details one of the approaches for developing educational hypermedia applications considered in this work: the Daphne model. Similar analyses were conducted for the EHDM and MAPHE.

- **Analysis of the Daphne Model According to the Proposed Guidelines**

The Daphne model [Kawasaki and Fernandes, 1996] aims at the development of hypermedia applications for educational purposes, focusing on the design of hypermedia knowledge domains. In order to deal with the pedagogical, navigational and presentation aspects related to this kind of application, Daphne incorporates concept mapping theory [Novak and Gowin, 1984, Novak, 1990], information mapping technique [Horn, 1989] and some ideas of the HDM model [Garzotto et al., 1993]. A methodology for describing how to systematically apply the model is also provided.

Concept maps are educational tools of great versatility [Novak and Gowin, 1984]. When constructing a concept map, it is possible to define the group of information that should compose the course, considering that learners may bring a degree of previous knowledge on the subject [Fernandes et al., 1999].

The use of the concept map technique allows structuring the knowledge domain of a hypermedia course in a graphic form, in which a node can represent either a concept or an example. In Daphne model however, the nodes are mostly used for representing concepts. Examples and other instructional elements are identified by applying the information mapping technique, discussed latter in this section.

Figure 2 illustrates a concept map representing the main concepts for the Musical Harmony knowledge domain. This map can be seen as a refinement of another map, more general, for Classic Music. In a similar way, some concepts represented in the Harmony map can also be detailed into more specific maps, if necessary. Notice that on elaborating a general concept map at first and then refining it into more specific and detailed maps corresponds to the establishment of an hierarchic structure
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for the knowledge domain. In fact, it can be seen as a mechanism for domain modularization.

As stated before, the hierarchical organization of the knowledge domain can be represented in a more specific way, by the establishment of concept taxonomies. In Daphne maps, this aspect is represented by the classification relationships. In Figure 2, a classification relationship can be observed among the concepts Chord, Consonant and Dissonant, where Chord represents the general concept. The same occurs for Musical Styles and their related concepts: Baroque, Classic, Romantic and Contemporaneous.

Except for the classification relationships, Daphne does not provide any kind of predefined relations. On the contrary, the relationships are domain-specific (user-defined). All relationships in Figure 2, except the classification ones, can be seen as domain-specific relations. Also, observe that the relationship formed by between the concepts Chord and Intervals represents the idea of concepts composition: Chord is a composed concept, formed by a set of Intervals.

Although the majority of the characteristics observed in the Daphne maps are concerned with conceptual aspects, some didactic features can be identified as well. For instance, the numbers near the concepts can
be used to give an idea of presentation sequence among them. Still in the same perspective, the concepts can be grouped as prerequisite, main body and complementary note, indicating a preliminary idea of concepts precedence.

In addition to the concept mapping, Daphne is also based on the information mapping technique [Horn, 1989]. The information mapping consists of dividing the information related to the nodes of a concept map into small portions of information, called maps. According to Horn [Horn, 1989], all basic information can be classified in seven types of information maps: concept, structure, procedure, fact, process, classification, and principle. In the same way, information maps can be divided into smaller parts, called blocks, which can assume a variety of types: definition, example, classification list, rule, synonym, theorem, exercise, and so on.

*Chord*, for instance, can be associated with two information maps: concept and classification. The concept information map can be divided into blocks of definition, notation, example, and exercise. The classification map can be specified in terms of its classification criterion and classification list.

The information mapping technique can be seen as a mechanism for specifying the internal structure of the concepts, providing a way to identify the relevant instructional information to be associated with each of them. In fact, the information blocks refer to the instructional elements to be linked with the conceptual objects.

Once the maps and blocks of each concept have been defined, it is necessary to elaborate their contents and, in this perspective, a storyboard can be designed. The storyboards can also be used to specify the applicative and structural links as well as some presentation aspects.

Mechanisms for accessing specific information in a direct manner, such as glossaries and analytical indexes, are provided by the model too. These mechanisms, called Direct Access Structures, are responsible for establishing a free navigation through the hypermedia contents. Regarding to the oriented navigation, it is available by designing the Programmed Access Structures. It is the case of guided-tours (or trails) in which a subject is presented in a pedagogic sequence, established according to a given learning purpose or learner’s profile. Notice that a guided-tour has some correspondence with the didactic model.

In the Daphne model, the main issues related to the navigational and presentation aspects are addressed with basis on the HDM ideas [Garzotto et al., 1993]. These aspects are not in the scope of domain modeling and, therefore, they will not be discussed in this paper.
It is important to highlight that Daphne focuses on the modeling and design phases of the development process of an educational hypermedia application. How to proceed on the implementation phase and what mechanisms and tools are more suitable for it should be established by the author.

5. CONCLUSION AND FURTHER WORK

Among the activities related to the learning materials development, domain modeling plays a significative role. This activity helps the author to identify the relevant parts of the subject knowledge domain, providing a systematic way to structure and organize the concepts and the relationships between them.

In this work we investigated the domain modeling activity under three different perspectives – conceptual, instructional and didactic. For each perspective, we established an initial set of guidelines which, in fact, imposes notation requirements for the domain modeling approach.

As a preliminary study, three approaches to the development of educational hypermedia applications – Daphne, EHDM and MAPHE – were analyzed according to the modeling aspects considered by the proposed guidelines. We could observe that each approach emphasizes a specific modeling perspective. For instance, the Daphne model, herein described in more details for the Musical Harmony domain, emphasizes the conceptual aspects, mainly considered when constructing the related concept maps. The instructional elements are treated by applying the information mapping technique, and the didactic aspects are considered when developing the programmed access structures. The EHDM method also deals with all modeling perspectives, but its emphasis is on the didactic aspects. The MAPHE methodology focuses in the conceptual aspects, mainly those related to the establishment of concepts taxonomies. Didactic issues are also discussed, but with a minor emphasis.

The ideas here discussed have been applied for modeling the conceptual, instructional and didactic aspects related to the Software Testing knowledge domain, in order to develop educational contents on this subject.

As a further work, we highlight the need to investigate how to proceed the abstraction of the reality when developing the domain models here discussed (conceptual, instructional and didactic). Other aspects, such as the presentation and navigational ones, related to the development of learning materials, should also be considered. In addition, we intend to investigate the use of ontologies in the context of educational content modeling as a mechanism to formally define and represent the concepts.
and relationships of a given knowledge domain, providing the semantics of its interpretation.

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