A knowledge-based model for instructional design

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Abstract. This thesis will discuss a knowledge-based model for the design and development of units of learning and teaching aids. The idea behind this work originates from previous theoretical work on ECM - Educational Concept Map (a logical and abstract annotation system, derived from the theories of instructional design), from the open issues in designing instructional authoring system, and from the lack of a well-defined process able to merge pedagogical strategies with systems for the knowledge organization of the domain.

Keywords: Knowledge Management, Topic Maps, Instructional Design, Semantic technologies

1 Problem Statement

Teaching and learning have undergone profound changes in recent years, partly a consequence of the evolution of learning theories, in part dependent on the development and evolution of network technologies. The emergence of constructivist theories of learning models [1] was accompanied by the evolution of the management of learning processes that have facilitated the dynamics of sharing and co-construction of knowledge. The evolution of this scenario prepared the ground to new challenges to research on issues such as interoperability and reusability of learning materials, accessibility, personalization, the definition of standards, quality, etc.

The basic idea that drove this PhD thesis starts from this awareness. The final goal is the definition and development of a knowledge-based model for instructional design with specific focus on educational content designed, to be used in e-learning environments, taking into account the perspectives of development that appears to promise the web today, grounded also on a pedagogical reflection and scientific knowledge we have today.

The approach proposed in this thesis finds its foundation in the work of those who in recent decades have addressed the problems underlying the processes of learning on the one hand and the other knowledge representation, with particular attention to the area of research that goes under the name of the semantic web.

The specific problem I address is a knowledge-based model for the design and development of units of learning and teaching aids. The idea originates from the analysis of the open issues in instructional authoring system, and from the lack of a well-defined process able to merge pedagogical strategies with systems for the knowledge

organization of the domain. In particular, the plan is to ground the work on the ECM - Educational Concept Map - model: a logical and abstract annotation system, derived from the theories of instructional design, developed with the aim of guaranteeing the reusability of both teaching materials and knowledge structures [2]. By means of ECMs, will be possible to design lessons and/or learning paths from an ontological structure characterized by the integration of hierarchical and associative relationships among the educational objectives. Within this context, I will address also the problem to find a "suitable" teaching and learning path through an ECM, i.e., a sequence of concept characterizing the subject matter under definition (a lesson or an entire course), and how these maps can be implemented by means of semantic web standards and technologies [3, 4, 5, 6].

An ECM has a two level structure: the level of concept, i.e. a model of representation of the subject matter where each topic can be associated (level of resources) with one or more resources describing the topic itself (documents, pictures, movies, ...). The plan is therefore to use the level of concept to automatically search relevant resources that are, in turn, associated to each topic of the level of concept in semi automatic way (by approval of the teacher). That is planned to do translating the ECM structure in RDF triples and activating web search extracting data from educational datasets by means of a combination of triples (see research questions).

2 Relevancy

The problems I address in this thesis are still open issues in instructional authoring system, and there is still a lack of a well-defined process able to merge pedagogical strategies with systems for the knowledge organization of the domain. By means of the logical and abstract annotation model of ECMs, it will be possible to design lessons and/or learning paths (see previous section). Once an ECM for a subject matter is defined by a teacher, the design of a lesson (for the teacher) and the surfing through a learning path for a student become a problem of topological sorting (on a graph) [7]. The possibility to make adaptive topological sort on an ECM become a powerful tool both for teachers, during the instructional design phase, and for students, during the learning phase.

Indeed, once an ECM is defined, the teacher can design a lesson adapting it on the previous background of its class, and a student can personalize the learning path depending on its specific knowledge and skills.

3 Related Work

This thesis addresses the problem of instructional authoring system from different point of view trying to integrate into a same model distinct aspects. From the pedagogical point of view, the framework of reference is that depicted by Stelzer and Kingsley in [8] and later revised in [9]; from the point of view of the representation of the subject matter the reference model is that of subject centric networks with specific focus on the Topic Maps model [10]; from the point of view of technology related

works are that carried out by projects and research consortia working on Topic Maps [3, 4, 5, 6]. The real difficulty is the integration between pedagogical and technological aspects in a common tool easy to be used by teachers and students.

4 Research Question(s)

The goal of this thesis is to development a system that assist the teacher for the design of a course by proposing a pliable model of domain knowledge on the base of a course (see relevancy) with the aim of guarantee the reusability of both the teaching aids and knowledge structure of a single disciplines. As to reusability, the ECM are designed to maintain the concept layer separate from the resources, making it possible to provide courses with the same CCM from the ECM but with different resources. Furthermore. for the implementation of efficient information search, metadata will be a central component and an pedagogical ontology describing the characteristics of the didactic resource will be defined. In TM metadata can be isolated and stored separately from the object, but still closely connected to the object. Since we need a representation of domain that can be seen from different points of view, each view showing a different structure, different set of parts, differently related [Prietula and Marchak, 1985] it seemed to us that TM are an appropriate abstraction for designing units of learning. Once an educational objective is define the system will assist the design of the course by automatically identifying the "prerequisites", in other words the concept that a student must know before attending a given unit of learning and the learning outcomes, on base of the relations (see approach). Still in assisting the teacher it remains an open problem how to propose and identify automatically resources to him/her. Accessibility, readability and searchability of web information are crucial for the semi-automatic extension of the knowledge base of our ECM. Integrating information from the two coexisting semantic web exchanging formats (RDF and TM) it's not a straightforward process, but our idea of web information retrieval is based on simplificate mapping of topics to RDF triples for RDF extraction of data from educational datasets. In order to propose to the teacher a possible sequence of topics where each topic can appear only once and cannot be preceded by any of his successors the systems implements a topological order modified algorithm that provides all the possible sequence of topological sorting (see approach). This is possible since between the units of learning and between the topics there could be a propedeutic relations (is-requirement-of) which is unidirectional relation that impose a precedence relationship that makes the unit of learning an acyclic graph.

5 Hypotheses

The availability of "sound" knowledge-based tools increases the productivity of teachers (time and quality) in the daily process of instructional design.

6 Preliminary results

The system is in the initial stage of implementation. The decision on the implementation framework to use for the development was conditioned on the usage of an open source framework that implements the TM standard possibly with active community. One further requirements was the mapping functionality of TM to RDF and vice versa. At first we focused on testing two open-source tools, Ontopia [5] and Wandora [6]; then we opt for building the system on top of Ontopia as being a well-established topic maps creation tool, with good reputation and with a powerful and flexible graphical presentation tool. The system besides the Ontopia engine for the creation of the TM and TM repository has a Resource Engine that handles the versioning and the metadata of the resources. Also further functionalities should be implemented for the topological ordering (see next section) and the assistance in the building of the CCM.

7 Approach

Educational Concept Maps (ECMs) are a formal representation of the subject matter structure in the context of learning environments, and a formal definition of the model is available in [2]. To understand the work of this thesis it is necessary, however, report here some concepts. An ECM is a logical and abstract annotation model created with the aim of guaranteeing the reusability of teaching materials, as well as of knowledge structures, and designed taking into account the pedagogical requirements defined by Educational Modeling Language research group [14]. It has been developed by means of an ontological structure characterized by the integration of hierarchical and associative relationships. Firstly, it asks teachers and instructional designers to focus their attention on learners' profile (in particular educational background, learning and cognitive styles) and objectives. Taking into account these elements, the model suggests how to identify, within the discipline's subject matter, the key concepts and their relationships so as to identify effective strategies of contents presentation and to support the activation of meaningful learning processes.

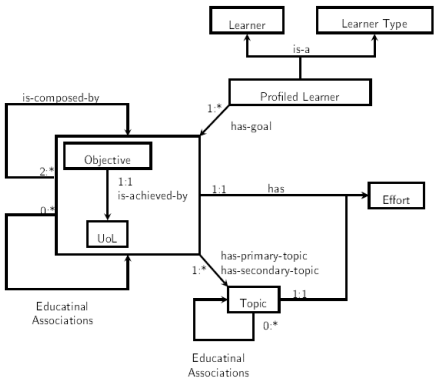

Fig. 1. CADDIE model

According to that model, a profiled learner has a goal identified by an objective (or a composition of objectives) that is achieved by a Unit of Learning (UoL), or by a composition of UoLs. The Course Unit (CU) is the indivisible union of an objective with its unit of learning and can be composed by creating the tree structure of the course (learning units, sub-learning units, etc.). The course units may be connected each other by means of the Educational Associations (EA) that may represent a link or a propaedeutic relationship the units have (see Fig. 1.). In particular, four types of EA have been identified:

· *is-requirement-of*: identifying a transitive and propaedeutic association between two or more topics (e.g., it may be used with the aim of specifying the logical order of contents);

· *is-related-to*: identifying a symmetric association among closely related topics (e.g., it may be used with the aim of creating learning paths without precedence constraints);

· *is-not-related-to*: identifying a symmetric relation of indifference between two or more topics (e.g., it may be used with the aim of making explicit the absence of association among topics);

· *is-suggested-link-of*: identifying not-closely related concepts (e.g., this relationship type may be used in order to suggest in-depth resources, internal or external to the contents repository).

These relation types have been defined with the aim of allowing teachers to create different learning paths (with or without precedence constraints among topics).

The same types of relationship can be found between topics. The latter are the smaller granularity of the ECM model. They represent the concepts of the domain: any subjects a teacher may want to talk about. Moreover, the units of learning are connected to the topics through two relationships:

o *has-primary-topic*: where a primary topic identifies the "prerequisites", in other words the concept that a student must know before attending a given unit of learning;

o *has-secondary-topic*: where secondary topic identifies the concepts that will be explained in the present unit of learning (this kind of topics will have specific learning materials associated).

In the ECM model, a course unit contains an educational objective and a unit of learning. Connected to the UoL there are the topics of the conceptual map describing the domain of the course itself. These topics can be both primary or secondary, depending on the context they are included in, within the unit of learning. Finally the secondary topics contain the material aid. Such resources, grouped in a unit of learning, enable to reach the objective connected to the UoL itself. The CUs allow the teachers to create complex nested structures using the EA.

The ECM model is the theoretical framework for the design of a system, currently in the implementation phase, with some innovative features described in the following:

1. The possibility to publish an Educational Concept Map on the Web and the relationships suggest the different navigation strategies of the underlying subject matter. The possibility to generate a linearized path, useful, for ex-

ample, for a teacher to produce a lesson or a document about a given subject matter. In this latter case, a *Suggested Paths Strategy* is necessary, to be expressed by means of is-requirement-of relationships.

To explain the strategy behind the Suggested Paths Strategy, let us also consider the idea of preparing a lesson on a given argument, using the previous ECM model.

The R_{req} (is-requirement-of) relationships order the topics *T* of the lesson according to the propaedeutics rules, therefore in the graph *G*=(*T*, *E*) there cannot be loops, thus obtaining a Direct Acyclic Graph (DAG), where *T* are nodes and *E arcs, with:* $(t_i,t_j) \in E \leftrightarrow R_{req}(t_i, t_j)$.

In this context, a *Topological Order* is a sequence $S = \{s_1, s_2, \ldots s_{|T|}\}$ where each element *T* appears only once and cannot be preceded by any of his successors; given pair of nodes (t_i,t_j) in S if there exists an arc from t_i to t_j, it follows that the node t_i is before the node t_j in the list: $\forall(t_i,t_j) \in S: (t_i,t_j) \in E \rightarrow i < j$.

The algorithm implementing the Topological Order is derived by Topological sorting algorithm [7] with a main modification in order to get all the possible sequences of topological sorting. Therefore we let the teacher to chose which of this sequences better answers the accomplishment of the didactic objectives. For as much as the topics are topologically ordered this doesn't take into account the distance factor in between the topics, thus a new element (Topic Aider - TA) is introduced in the sequence S before the distant topic to recall the subject. The TA could be an exercise, an example, a text or a valuation test. This recall is also reported in the final sequence in order to highlight not only to the teacher, but also to the student the place where s/he should evoke an determinate argument. The choice to have not a single path but a list of paths to suggest to the author leaving the final choice to the author him/herself, is also to answer to the non-equifinality problem posed in [15]. The "suggested" order lists is on the basis of the principle of reducing as much as possible the distance between two topics of the list that are contiguous on the graph.

In order to implement such a model, Topic Maps (TM) has been chosen. TM is an ISO multi-part standard [3] designed for encoding knowledge and connecting this encoded knowledge to relevant information resources. The standard defines a data model for representing knowledge structures and a specific XML-based interchange syntax, called XML Topic Maps (XTM) [4]. The main elements in the TM paradigm are: *topic* (a symbol used to represent one, and only one, subject), *association* (a relationship between two or more topics) and *occurrence* (a relationship between a subject and an information resource).

Therefore, two layers can be identified into the TMs paradigm:

- the *knowledge layer* representing topics and their relationships, allowing to construct the ECM model;
- the *information layer* describing information resources, to be attached to the ECM topics.

Each topic can be featured by any number of *names* (and *variants* for each name); by any number of *occurrences*, and by its *association role*, that is a representation of the involvement of a subject in a relationship represented by an association. All these features are statements and they have a *scope* representing the context a statement is valid in. Using scopes it is possible to avoid ambiguity about topics; to provide differ-

ent points of view on the same topic (for example, based on users' profile) and/or to modify each statement depending on users' language, etc. Therefore, to solve ambiguity issues, each subject, represented by a topic, is identified by a *subject identifier*. This unambiguous identification of subjects is also used in TMs to merge topics that, through these identifiers, are known to have the same subject (two topics with the same subject are replaced by a new topic that has the union of the characteristics of the two originals).
The knowledge layer can also be used, as introduced in the Problem Statement section, to automatically search relevant resources that are, in turn, associated to each topic of the information layer in semi automatic way (by approval of the teacher).

8 Evaluation plan

The system is presently in a first stage of implementation. Particular attention will be paid to the design and implementation of the user interface. There is a plan during the second half of the next year of my PhD course to experiment the prototype of the system within a selected teachers of EPICT community (www.epict.it), a large community of teachers of the Italian secondary schools. The plan is to measure both the usability of the user interface and the instrument's effectiveness in terms of improving the work of the teacher. In particular, it will seek to evaluate the improvement of daily activities of instructional design carried out by the teacher in terms of both the reduction of design time, and of increased efficacy of the process of instructional design.

I will prepare questionnaire to collect quantitative data, deepen then the results with focus groups.

The experience of teachers with this system will be compared with the previous experience of the same teachers

9 Reflections

The idea behind this thesis has been stimulated by the real "needs" of a community of teachers to have model and tools that facilitates some phases of instructional design. Since the concept representation is independent of its implementation, ECM lends itself for reusability of both teaching materials and knowledge structure. Thus the knowledge structure could be reused for the design of a different course according to the learner target, and new resources could be automatically proposed for the information layer, hence semi-automatically populating (by approval of the teacher) the course map. From student point of view, the subject-centric nature of the TM help learners to identify core concepts, while the extended TM with the learning path assists the student for proper order sequence of studying. Moreover, the underlying model, ECM, is grounded on pedagogical reflections. For these reasons we believe that this model will have a good acceptance by the community of teachers we plan to select for the testing phase.

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