Applications

A formal instructional model based on Concept Maps

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Abstract

The aim of this paper is to show a new model (under development by the E-Learning & Knowledge Management Laboratory at the University of Genoa) for designing and developing units of learning. The idea behind this model comes from the analysis of the difficulties and problems that teachers have in their work during the instructional design of courses and training aids, and from a study on the latest semantic web technologies in order to support the sharing and the retrieval of web learning resources.

The authors will also present the draft version of CADDIE (Content Automated Design & Development Integrated Editor), a software tool under development at the E-Learning & Knowledge Management Laboratory of the University of Genoa, whose core is based on the model described here and whose aim is to provide an innovative solution to the learning content of the instructional design process, based on an ontological structure.

1 Introduction

E-learning, or web-learning, represents an interesting way of developing learning paths in various contexts (companies, public administrations, schools and universities); it can also offer some concrete benefits, such as speed, flexibility, customization, control of the learning process and, above all, a wider diffusion and lowered costs.

Educational resources for web-learning should be developed to ensure the fulfillment of the following four main requirements: modularity, interactivity, completeness and interoperability. Therefore, designing and developing of teaching aids and/or lessons for distance-learning place a greater workload on the teacher than the "traditional" lessons in presence. In order to reduce this workload, teachers can use web technologies to access more quickly and flexibly educational resources and also easily share these materials with colleagues and students.

Nowadays, editor tools for instructional content design are often oriented to the use and/or reuse of resources, helping teachers in a more or less assisted concatenation of materials already available or created by the teacher himself. Learning objects generated in this process are accessible within a sequence of resources, or links between them (e.g. web pages), but do not allow to make explicit the underlying knowledge structure. This methodology greatly reduces the reusability and adaptability of learning objects and paths. We can define this methodology as a "bottom-up": teachers start from the resources to design an entire course or several lessons. In this case, the reusability of this work is restricted to the same course or to a single lesson.

Therefore, an authoring tool is necessary to allow teachers to create courses, lessons or units of lesson, not starting from resources, but rather from learning objectives; and only in a second moment, authors will add the resources required for the achievement of these objectives. This approach could be named "top down": from the course domain conceptualization to the design of the educational resources. This methodology requires firstly the definition of a contents schema, based on the key concepts and on the relationships among them. It is a knowledge representation model of the course subject matter, which represents a kind of deep structure (Chomsky N., 1955) to be binded to the specific content.

2 Knowledge representation in web-learning

One of the most suitable knowledge representation models for learning content design is certainly the Concept Maps model. It allows both teachers and learners to browse knowledge structures by means of a graphical representation. It facilitates the generation and representation of ideas, making explicit the logical paths of reasoning or mental construction also through a graphical visualization. Concept Maps are a static knowledge representation model, such as a photographic representation of the physical world, but they also have a dynamic value, as a representation of cognitive processes. Generally, it is difficult to reenact the dynamics of the author's (painter, poet, writer,...) internal processes that lead to the final version of his/her work, because it assumes a very subjective practice that reflects inferential processes such as deduction, induction, and abduction. In the human mind, data are not organized sequentially, but in an analogical and associative way, emulating the brain structure. For these reasons, it is considered that the most suitable representation model able to describe a grid of knowledge is a map. Concept Maps permit to:

- describe thought processes that are represented in the same way as they are structured in human mind (concepts linked to each other in a not linear way);
- facilitate the reconstruction of logical paths, allowing authors to share knowledge with others and supporting a better communication;
- convert the (sequential) verbal communication into a visual and multidimensional representation which shows the whole logical path structure (with different abstraction layers);
- go through these different (abstraction) layers;
- explode a node of the map for in-depth examination and link it to another map for a better elaboration of the concept.

As a consequence, from a pedagogical perspective, a map is a useful tool for the achievement of meta-cognitive competences, i.e. a set of skills that allows students to increment knowledge, making explicit what is implicit through meta-cognition (learning to learn). There are different types of maps, among which Concept Maps fit best for educational purposes. The design methodology for Concept Maps was developed by Joseph Novak in the 60s (Novak J.D., 1998), re-examining Ausubel's learning theory of the years 40-60 (Ausubel D. P., 1963). According to his theory, knowledge is organized in a complex structure in which more specific concepts are included into more general ones. The concepts linked together in a hierarchical and associative way generate new meanings. Concepts and relationships between concepts are therefore the Concept Maps key elements.

As mentioned before, Concept Maps have a great educational value: they push the author to reason out on his own knowledge, to establish links between ideas and to link this knowledge to the available data, supporting communication processes and the intuitive perception of knowledge structures. Therefore, Concept Maps function as a support for creating and representing knowledge in order to achieve a meaningful learning process.

3 Educational Concept Maps

In this section, a conceptual-logical model for instructional content design is introduced (it is based on the knowledge representation models which have been discussed in the previous paragraph).

It is a logical and abstract annotation model, derived from fundamental theories of instructional design, created with the aim of guaranteeing the reusability not only of teaching materials, but also of knowledge structures (moving the generalization level from the contents to the definition of the contents' schema). This model, developed by means of an ontological structure characterized by the integration of hierarchical and associative relationships, asks teachers and instructional designers to focus their attention on the learners' profile (in particular educational background, learning and cognitive styles) and objectives. Considering these elements, the model suggests identifying, within the discipline's subject matter, the key concepts and their relationships so as to identify the most effective strategies of contents presentation and to support the activation of meaningful learning processes. Subsequently to the Concept Map design, that is named Educational Concept Map (ECM), it is possible to associate educational resources to the single nodes (for example, Learning Objects, text documents, audio and/or video files, etc.).

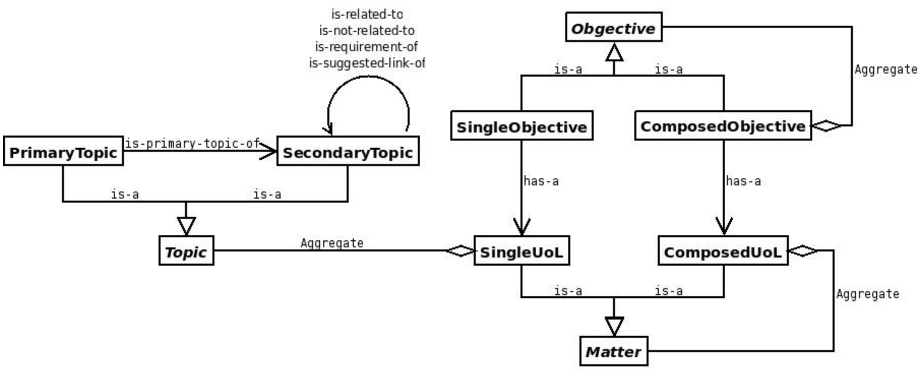

Fig. 1 - The Educational Concept Map

Educational objectives, according to the model, can be represented as SingleObjective or ComposedObjective, depending on the fact that they are single objectives (not decomposable into sub-objectives) or composed-objectives constituted by two or more sub-objectives. Single units of learning including topics (SingleUoL) will be associated to the first class; while composed units of learning (ComposedUoL) including SingleUoL or ComposedUoL will be linked to the second class. As shown in figure 1, the model is based on a hierarchical and recursive organization (through the is-a relationship) of learning objectives to which corresponds a layered structure (n levels with n integer positive) of contents. Moreover, it is worth noticing that the relationship between an objective and a unit of learning is always necessarily a 1:1 association (a SingleUoL corresponds to a SingleObjective).

In conformity with this scheme, SingleUoLs represent the units of learning at the finest level of granularity.

The previously mentioned recursive structure has been defined with the aim of maximizing the flexibility of the learning design process (making the model suitable both for the development of learning paths and teaching materials). An Educational Concept Map can be therefore defined by the syntax:

<RCD>::= <UoL>+
<UoL>::= <SingleUoL> | <ComposedUoL>
<SingleUoL>::= <Topic>
<ComposedUoL>::= <RCD>
<Topic>::= *PrimaryTopic* | *SecondaryTopic*

In addition, it is possible to define propaedeutic relationships between two objectives, and, as a consequence, there will be an equal association between the corresponding units of learning (SingleUoL or ComposedUoL) belonging to the same ECM. The binary relationship has the form

Rel(*<UoL1>*, *<UoL2>*).

Once the logical and chronological scheme of educational objectives is determined, it is possible to identify and organize the schema of contents based on a taxonomic learning units organization (in fact, each objective is pursued through the corresponding UoL).

Then, for each unit of learning, the ontology needs to specify the topics, the key-concepts on which the UoL is focused. As shown in figure 1, topics can belong to the two following classes:

- PrimaryType: this class identifies the "prerequisites", in other words the concepts that the student must know before participating in the course (the set of these topics, which will not have instructional resources associated, represent the knowledge-requirement of the course);
- SecondaryType: this class identifies the concepts which will be explained in the course (this kind of topics will have specific learning materials associated).

The Rel relationship which establishes a connection between a primary topic and a secondary topic is named is-primary-topic-of. Primary topics have to be specified for each unit of learning at a local level, in order to allow the UoLs reusability in various instructional processes. This fact has as a consequence that the same topic x could be considered as a primary topic within a unit of learning A, and as a secondary topic in a different unit of learning B. Relationships among secondary topics can be:

- is-requirement-of: it identifies 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: it identifies 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: it identifies 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 between topics);
- is-suggested-link-of: it identifies 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 selected with the aim of allowing teachers and instructional designers to create different learning paths (with or without precedence constraints between topics).

Similarly, it is possible to define the "learning outcomes" of an ECN as:

$\forall t_j \in T: \neg\exists$ is-requirement-of(t_j, t_n) per $\forall\, t_n \in T$: n = 1.. j-1, j+1.. k.

An Educational Concept Map allows us to create learning paths and instructional resources more easily interoperable and reusable, because the concept representation is independent from its implementation. The same concept network could be used for designing different courses (obviously, belonging to the identical knowledge domain). It could be possible to deliver a course whose content needs to be personalized according to different learners (with different educational objectives, skills and pre-knowledge). In this scenario, the course Concept Map holds steady, and what changes are the specific instructional resources associated.

4 From the model to its implementation

Once the logical model has been defined, an analysis of knowledge representation languages and formalisms is performed with the aim of identifying the most suitable one for its implementation. To this purpose, different models and languages developed in the context of the Semantic Web (Shadbolt *et al.*, 2006) field have been taken into account, so as to describe the Concept Map and the resources associated in a standardized and formal way, and to improve the data reusability and interoperability. At this moment, the encoding scheme which has seemed mainly consistent with the project's goals, and most suitable because of its expressive capacity, is the ISO/IEC 13250 Topic Maps.

Topic Maps (TM) are an ISO multi-part standard designed for encoding knowledge and connecting this encoded knowledge to relevant information resources (ISO/IEC13250, 2003). The standard defines a data model for representing knowledge structures and a specific XML-based interchange syntax, called XML Topic Maps (XTM) (Pepper, 2000).

The main elements in the TM paradigm are: topic, association and occurrence.

According to ISO definition, a topic is a symbol used within a topic map to represent one (and only one) subject, in order to allow statements to be made about the subject, that can be <<*anything whatsoever, regardless of whether it exists or has any other specific characteristics, about which anything whatsoever may be asserted by any means whatsoever*>>.

An association represents a relationship between two or more topics.

An occurrence is a representation of a relationship between a subject and an information resource.

The subject in question is that represented by the topic which contains the occurrence (for example, an occurrence could be a webpage, a book, an image, a movie depicting the subject) (Pepper, 2000). Therefore, two layers can be identified into the TM paradigm:

- knowledge layer that represents the topics and their relationships, and
- information layer that describes the information resources.

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 have a scope that represents the context within which a statement is valid. Using scopes it is possible to remove topic ambiguity; to provide different points of view on the same topic (for example, based on the users' profile) and/or to modify each statement depending on the 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 TM 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 Topic Maps paradigm and XTM have been proven to be very expressive and flexible, and for these reasons have been exploited within the CADDIE

(Content Automated Design and Development Integrated Editor) project (Adorni *et al*, 2007), where they support the learning paths and resources design (by means of Concept Maps composed by topics and associations).

Graph linearization is another relevant issue which needs to be considered, to take into account technological constraints regarding, for example, the respect of standards requirements (such as the ADL SCORM), and in order to support the learning process tracking by means of a Learning Management System. Relationships used in the model previously discussed can be automatically processed and linearized, with the aim of extracting different learning paths (thanks to the information about sequentiality between topics).

These constraints, however, do not restrict the possibilities for teachers and instructional designers to identify the most effective strategies of contents presentation in different educational scenarios, because it is always allowed to modify the topics sequence in all the steps of the learning design process.

5 Learning resources and semantic indexing

Once an Educational Concept Map has been defined and formalized according to the XTM standard, it is possible to go ahead with the map population with learning resources. These latter must be properly indexed to allow the searching and the sharing of the resources themselves.

For this purpose, an educational ontology, independent from the knowledge domain, is under development for the semantic indexing of learning resources. This ontology derives from a model applied in the context of the AquaRing UE project (Bianchi *et al*., 2009), which in turn was derived from some controlled vocabularies (a limited sets of terms used for indexing documents) and metadata standards, in particular the IEEE LOM (Learning Objects metadata) and the POEM Model (Pedagogy-Oriented Educational Metadata) (Alvino, 2008). The first one is an IEEE-2002 standard; the second one is an application profile, based on the IEEE LOM, with a strong emphasis on pedagogical features. The development of an ontology compliant with international standards will entail the interoperability and maintenance of learning aids repositories.

On the base of the ontology-based indexing, CADDIE will be able to perform automated analysis on available resources tagged with this metadata model and select the most appropriate educational objects according to the students' profile and the educational objectives.

6 Conclusions

In this paper, some topics related to the instructional content design process have been discussed. The model previously introduced is at the basis of the CADDIE - Content Automated Design & Development Integrated Editor – framework, which is under development at the E-Learning & Knowledge Management Laboratory of the Department of Communication Computer and System Sciences of the University of Genoa.

This application uses Educational Concept Maps, based on Topic Maps standards, for the design and the development of learning paths and related teaching aids.

CADDIE framework can help teachers and/or instructional designers at different stages of their work:

- macro-design of courses or single units of learning by means of the Educational Concept Map model;
- micro-design linking resources to topics into the map;
- editing and/or development of learning resources;
- semantic-based indexing of resources;
- Educational Concept Map browsing (at different abstraction levels) and linear paths extraction from a topic network;
- development of knowledge domain ontologies by means of Educational Concept Maps.

These features, combined with the benefits deriving from a formalized and standardized XML description of Educational Concept Maps, provide a flexible framework supporting the development of a resources repository for learning objects that can be easily updated and shared.

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