Educational Concept Maps: a Knowledge Based Aid for Instructional Design

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***Abstract*—This paper discusses a knowledge-based model for the design and development of units of learning and teaching aids. The idea behind this model originates from both the analysis of the open issues in instructional authoring systems, and the lack of a well-defined process able to merge pedagogical strategies with systems for the knowledge organization of the domain. In particular, it is presented the Educational Concept Map (ECM): a, pedagogically founded (derived from instructional design theories), abstract annotation system that was developed with the aim of guaranteeing the reusability of both teaching materials and knowledge structures. By means of ECMs, it is 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. The paper also discusses how the ECMs can be implemented by means of the ISO/IEC 13250 Topic Maps standard. Based on the same model, it is also considered the possibility of visualizing, through a graphical model, and navigate, through an ontological browser, the knowledge structure and the relevant resources associated to them.**

Keywords- Instructional design, Knowledge representation, Instructional Authoring Systems, Topic Maps

I. INTRODUCTION

The recent evolution of Web-based technology has dramatically changed the learning processes and, consequently, e-learning. Nowadays, on the one hand learners can access information and knowledge sources that are practically unlimited, can share their learning experiences, and collaborate within dedicated social networks in order to better achieve their instructional objectives. On the other hand, teachers and instructional designers can access large repositories in order to retrieve and share learning assets, and can use authoring tools for designing Web-based educational paths. As a consequence, new models are required in order to support meaningful learning processes, based on the assimilation of new concepts and propositions into existing cognitive structures. The role of subject matter analysis and knowledge reusability has been long recognized by instructional designers with the aim of supporting meaningful learning processes through a careful knowledge selection, organization, and sequencing [1]. In this scenario, one of the most relevant problems concerns the fact that there are no canonical representations of knowledge structures and that a knowledge domain can be structured in different ways, starting from various points of view. As Ohlsson [2] highlighted, this fact has such relevant implications for authoring systems, that it should be stated as the "*Principle of Non-Equifinality of Learning*". According to this, "*The state of knowing the subject matter does not correspond to a single well-defined cognitive state. The target knowledge can always be represented in different ways, from different perspectives; hence, the process of acquiring the subject matter have many different, equally valid, end states*". Therefore it is necessary to re-think learning models and environments in order to enable users to better build represent and share their knowledge.

II. THE EDUCATIONAL CONCEPT MAP MODEL

For the formal representation of the subject matter structure in the generic context of learning environments, the Educational Concept Map (ECM) model (see Figure 1) is herein introduced. This model was developed by keeping into account the following pedagogical and technical requirements [3]: *i) pedagogical flexibility*: the model must be able to describe the structure of instructional contents regardless of a specific learning theory; *ii) learner centrality*: the instructional content design process must be based on students' profile and needs; *iii) centrality of learning objectives:* the instructional content design process must be based on a preliminary definition of the learners' pedagogical objectives; *iv) personalization*: the model must be able to design learning contents and resources in a flexible way, consistently with learners' profile; *v) domain-independence*: the model must be able to describe instructional content regardless of its disciplinary nature; *vi) reusability*: the model must allow to define and de-contextualize learning content structures and to reuse these in other contexts; *vii) interoperability*: the model must be language-independent, so that it can be implemented through different knowledge representation languages and exported in different learning environments; *viii) medium neutrality*: the instructional contents design process must be medium neutral, so that it can be used in different publication formats; *ix) compatibility*: the model must fit in with existing standards and specifications on learning resources; *x) formalization*: the model must describe instructional content according to a formalized model, so that automated processing is possible.

The ECM is a logical and abstract annotation model created with the aim of guaranteeing the reusability of both teaching materials, and knowledge structures. It shifts the generalization level from the contents to the definition of the relevant schema. It derives from fundamental theories of instructional design that can only be briefly sketched in the following. According to Merrill [4] and Gagné [5], once the learner profile is known, the instructional design process should start from the definition of a hierarchical organization of learning objectives describing what learners should know or be able to do at the end of the instruction. Such a hierarchy of learning goals provides the general framework for the selection of contents. The preliminary organization of learning objectives and contents into a hierarchical structure (thus making explicit the logical order of learning content) is also considered in Ausubel [6] works. He introduced the notion of *"advanced organizer"* as a way to provide the cognitive structure or, in other words, the mental scaffolding during meaningful learning processes. According to this theory, new concepts to be taught should be introduced by more general and inclusive concepts.

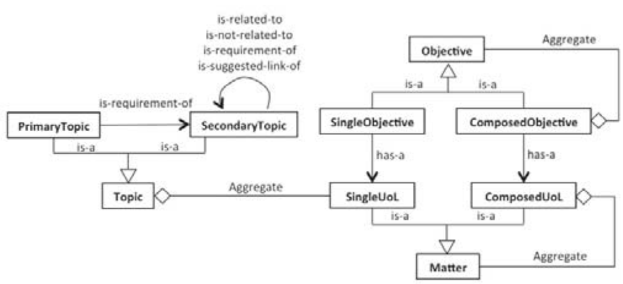

Figure 1 The ECM Model

Referring to such a theoretical framework, the ECM model 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' objectives and on their profile, described in terms of educational background, as well as of learning and cognitive styles. 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 [7].

According to the ECM model, a profiled learner has a goal identified by a specific objective (single or multiple) 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. In particular, four types of EA have been identified: *i) 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); *ii) 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); *iii) 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); *iv) 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 selected 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: (i) *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; (ii) *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).

More formally, given D the set of all topics in the ECM and U, sub set of D of topics $\{t_1, \ldots, t_n\}$ of the same UoL, one can obtain the set P of primary topics:

$$t \in P \Leftrightarrow \exists t_i \in U : is-requirement-of(t, t_i)$$

In a similar way, one can identify the set L ($L \subseteq U$) of "learning outcomes", i.e., the specific intentions of a unit of learning. Given $t_j \in U$:

$$t_j \in L \Leftrightarrow \forall \neg \exists t_i \in U : is-requirement-of(t_j, t_i)$$

with $i = 1, i-1, i+1, \ldots n$.

So, 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 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 and nested structures using the EA.

Furthermore, an ECM can be published on the Web and the relationships suggest the different navigation strategies of the underlying subject matter. More precisely, each Web page related to a topic contains i) one or more links to topics that are considered propaedeutic of this ECM (through the *is-requirement-of* relationship); ii) link to related topics (through the *is-related-to* relationship), iii) links to suggested readings or further topics (through the *is-suggested-link-of* relationship). Such a map can also be used to generate a linearized path, useful to produce a lesson or a document about a given subject matter. In this latter case, a *Suggested Path Strategy* is necessary, to be expressed by means of *is-requirement-of* relationships. Differently from some of the aforementioned EMLs, the ECM model enables authors to define alternative learning content presentation strategies, in order to provide personalized learning paths, depending on specific needs. The definition of this strategy, introduced also in reply to the *non-equifinality problem*, derives from the *Cognitive Flexibility Theory* [8], stating that learning processes (especially in ill-structured and complex domains) require a multiple representation of content and the *criss-crossing* of the conceptual landscape which should be revisited from different directions, with the aim of acquiring an advanced knowledge.

In order to fully exploit the potentiality of such a model, a formalization for the ECM is needed, to effectively represent the model. Among the many possible, the Topic Maps standard [9] has been adopted as the knowledge representation language for the implementation of the above model. Topic Maps (TM) are an ISO multi-part standard 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) [10]. The main elements in the TM paradigm are: *topic*, *association* and *occurrence*. According to the ISO definition, a Topic is a symbol used within a TM to represent one -and only one- subject, in order to allow statements to be made about the subject. An Association represents a relationship among two or more topics. An Occurrence is a representation of a relationship between a subject and an information resource. In this vein, the TM standard is based on the simple paradigm of TAO: *Topic*, *Association* and *Occurrence* [11; 12]. Therefore, two layers can be identified into the TMs paradigm: (i) the *knowledge layer*: representing topics and their relationships, allowing to construct the ECM model; (ii) 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. All of these features are statements and they all have a scope, representing the context a statement is valid in. Then, using scopes it is possible to avoid ambiguity about topics; to provide different 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, which is represented by a topic, is associated 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; in practice, two topics with the same subject are replaced by a new topic that has the union of the characteristics of the two originals.

III. THE ECM VISUALIZATION

As stated in the previous section, Topic Maps are a very powerful means of representation, but they may be difficult to use. Intuitive visual user interface may significantly reduce the cognitive load of teachers. In the recent years, different relevant initiatives have been carried out to formalize the graphical notation of topic maps, such as GTM (*Graphical Topic Maps notation*) and TMMN (*Topic Map Martian Notation*). The former, specified in ISO 13250-7 (the part 7 of the Topic Maps ISO Standard), is a graphical notation defining ontologies and representing TM instance data. The latter is an alternative simple graphical notation, currently under development, able to express the Topic Maps Data Model that can be adopted with the aim of representing both ontologies and instance data on whiteboard, a paper, as well as within a diagram-based software.

With reference to the ECM visualization requirements, the main goal is to help teachers to quickly navigate an ECM, to group the topics in a *Unit of Learning* and to compose the course structure in an easy and intuitive way. Thus, there are two types of requirements for TM visualization: topics representation and navigation. The first helps teachers to identify points of interest, while the latter allows accessing information rapidly.

First of all let us identify the different kinds of views that a teacher may need. These views reflect the different approaches and steps to the activity of course planning and development. During the *planning*, when the teacher is defining the macro-aspect of a course, he/she must be able to navigate the Course Units structure, create new units, and change the relevant associations. In the *design* of a unit of learning, a teacher needs to explore the domain of knowledge and to add topics to the *UoL*.

Therefore, two different layers of Topic Maps can be considered: the layer of Course Units and the layer of Topics. In the first, the Course Units and the associations among them are represented. In the second one, there are all the topics belonging to the domain. The two layers are strictly connected through the relationship *has-{primary,secondary}-topic* as described before. Two layers offer a better view of the problem and a better way of information retrieval; merging course units and topics in one only topic map increase the complexity and reduce the re-usability of the map in different contexts. Moreover a teacher needs an overall view of the two layers, so to understand them globally. There would be two different overviews (course and topic) that should reflect the main properties of the structure. However, the teacher should be able to focus on any single part of the TM.

In order to support the knowledge structure navigation, the use of XTM makes possible to explore the ECM. Several TM engines provide suited visualization tools. Most of them display lists or indexes, from which it is possible to select a topic and to see related information. This representation is very convenient when users' needs are clearly identified. The navigation is usually the same as on Web sites, i.e., users click on a link to open a new topic or association. An example of such visualization is the one provided by Omnigator (part of the Ontopia Knowledge Suite), a Web-based Topic Maps browser (with RDF support) allowing both teachers and learners to display in a meaningful way the learning contents. It also allows following different learning paths, according to the specific educational purposes that have been defined. Finally, the same browser can be exploited with the aim of: i) merging different ECMs, on the fly; ii) searching learning content within the knowledge structure; iii) exporting this latter to various syntaxes; iv) personalizing different views; v) filtering subsets of topics according to different scopes.

As an alternative solution, in order to facilitate the visualization and the understanding of ECMs, it is also possible to integrate specifically designed plug-in, such as the Vizigate, offering an intuitive graphic visualization of the learning content. In Vizigate topics are nodes and their type may be symbolized by different colors, shapes and textures. However, the number of different shapes, colors and icons is limited. Class hierarchies can be used to reduce topic types to a small number of "*super-types*": *Course Unit, Unit of Learning* and *Topic* in the ECM; in this case, we only need a specific shape and/or color for each super-type. In the same way, the *is-related-to*, the *is-requirement-of*, and the other Educational Associations could be drawn differently, so that they can be quickly recognized by the teachers. The EAs are binary relationships, so they could be arcs and their type may be symbolized by the style of lines (e.g., full line, dotted line, etc.). Currently, the topic map standard does not suggest a standardized way of specifying type hierarchies. However, this could be done in Vizigator, an application based on the Vizigate, by using a kind of a style-sheet mechanism. This would allow to specify which association types represent the *supertype/subtype* relationship for any given topic map.

In Vizigator a mouse left-click event can display topics and associations names and types when the cursor is over these elements. Moreover, a right-click on a topic displays several additional information and permits the user to expand, collapse or navigate all the elements of that type. The heart of Ontopia is the Ontopia Topic Maps Engine on which all the other components are based. The basic functionalities of this engine are in representing, storing, and making available topic maps to the rest of the product suite. In addition, the engine also provides a rich set of APIs against which TM-based applications can be built. Moreover, Ontopia includes a Query Engine, built upon the Tolog query language. For retrieving information from the topic maps, the query language is far best suited than the API. It makes the task much easier, while at the same time, enables far better performance, since the query engine can take shortcuts not available to applications working through the API. As an example, let us consider the idea of combining the Vizigator API, that is a good tool for Topic Maps navigation, with the Ontopia Core Engine API, which offers several methods for the manipulation of TM and uses the Tolog language for machine reasoning and course sequencing. Then, an effective visualization and enquiry tool can be made available as a mash-up application.

IV. Conclusions

The ECM allows creating learning paths and instructional resources more easily interoperable and reusable, owing to the fact that the concept representation is independent of its implementation. In addition, the same concept network can be used for the design of different courses. Such an approach is suited to deal with the problem of delivering a course whose content needs to be personalized according to different learners needs. Moreover, an ECM drawn with reference to a specific subject matter can be used also to publish directly on the Web the underlying subject matter with links to prerequisites and related or suggested topics, or it can be used to generate linearized paths useful to produce a lesson or a printable document [13].

Graph linearization is another relevant issue to be considered, to take into account technological constraints regarding, for example, the compliance with 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 previously discussed model can be automatically processed and linearized, with the aim of extracting different learning paths (thanks to the information 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.

References

[1] Merrill, M. D. (2002). Knowledge objects and mental models. In D. A. Wiley (Ed.), The Instructional Use of Learning Objects (pp. 261-280). Washington DC: Agency for Instructional Technology & Association for Educational Communications and Technology.

[2] Ohlsson, S. (1987). Some principles of intelligent tutoring. In Lawler, R.W., and Masoud Yazdani, M. (eds.), Artificial Intelligence and Education: Learning Environments and Tutorial Systems v. 1, Intellect Books.

[3] Koper, R. (2001). Modelling units of study from a pedagogical perspective: the pedagogical metamodel behind EML. Heerlen: Open Universiteit Nederland. Retrieved from http://dspace.learningnetworks.org/handle/1820/36?mode=simple

[4] Merrill, M. D. (2002a). First Principles of Instruction. ETR&D, Vol. 50(3), 43-49.

[5] Gagne, R. M. and Briggs, L. J. (1979). Principles of Instructional Design. New York: Holt, Rinehart and Winston.

[6] Ausubel D. P. (1963). The psychology of meaningful verbal learning. New York, Grune and Stratton.

[7] Adorni, G., Brondo, D., Vivanet, G. (2009). A formal instructional model based on Concept Maps. Journal of E-Learning and Knowledge Society, Vol. 5(3), 33-43.

[8] Spiro, R. J., Coulson, R. L., Feltovitch, P. J., and Anderson, J. K. (1988). Cognitive flexibility theory: advanced knowledge acquisition in ill-structured domains. Patel, V. (ed.) Proceedings of the 10th Annual Conference of the Cognitive Science Society. Hillsdale, NJ: Lawrence Erlbaum.

[9] ISO13250 (2003). ISO/IEC 13250:2003: Information Technology - Document Description and Processing Languages - Topic Maps. International Organization for Standardization, Geneva, CH. Retrieved from http://www.y12.doe.gov/sgml/sc34/document/0322_files/iso13250-2nd-ed-v2.pdf

[10] Pepper, S. and Moore, G. (2001). XML Topic Maps (XTM) 1.0. Retrieved from http://www.topicmaps.org/xtm/1.0

[11] Pepper, S. (1999). Navigating Haystacks, Discovering Needles. Markup Languages: Theory and Practice, Vol. 1(4), MIT Press.

[12] Ontopia (2002), Learn more about topic maps. Retrieved from http://www.ontopia.net/topicmaps/learn_more.html

[13] Adorni, G., Coccoli, M., Vercelli, G., Vivanet, G. (2008). Semantic authoring of learning paths with Topic Maps. In Proceedings of DMS 2008, the 14th International Conference on Distributed Multimedia Systems, Knowledge Systems Institute Graduate School, ISBN/ISSN: 1-891706-23-3, Boston, Massachusetts, U.S.A., Sept. 4-6, 2008.