Machine-supported Instructional Design

George Mavrommatis

Abstract—**Educational Technology is currently developing under the advent of Learning Objects. Standards are evolving, and the future of learning seems to integrate with Information and Communication technologies via this general notion. It is expected that, sooner or later, a large number of Learning Objects will be available in databases, for use by teachers and learners. Yet, towards this target, many issues are still waiting to be answered. Among them, the integration of Instructional Design and Learning Theories into the Learning Objects search procedure and course creation, is of great importance. This paper describes a simple mathematical framework that models selected Learning Theory methodologies into the Learning Objects search procedure and sequencing.**

Index Terms—**Education, Learning Objects, Instructional Design, Distance Learning, Information Retrieval.**

I. Learning with Objects

Among the different issues that modern e-learning is dealing with [1], creation of standards, specifications, and applications based on these standards, plays a major role. There are several organizations, initiatives and projects aiming towards this certain direction. The list includes, among others, the IMS Global Learning Consortium, the Aviation Industry CBT Committee (AICC), the Alliance of Remote Instructional Authoring and Distribution Networks for Europe (ARIADNE), the Advanced Distributed Learning (ADL) Consortium, The Dublin Core Metadata, the IEEE Learning Technology Standards Committee (LTSC), the Multimedia Educational Resource for Learning and Online Teaching (MERLOT), the Open Knowledge Initiative (OKI), the Content Object Repository Discovery and Registration/Resolution Architecture (CORDRA). For a more detailed list, together with other resources about Learning Objects, see [2].

In 1997, the US Department of Defense created the ADL Consortium in order “to develop the standards, tools and learning content for the learning environment of the future” [3]. The SCORM standard came out of this consortium [4]. It derives from, and references specifications developed by other organizations, mainly ARIADNE, AICC, IEEE LTSC, IMS. SCORM is considered as the “state-of-the-art” of the standardization effort. As stated, it describes models for learning objects in order to support adaptive instruction [4]. The most recent version also contains a Sequencing & Navigation related book.

Although there is no common, widely accepted, definition of Learning Objects (LO), the notion is not really new: It is a common practice for teachers to break the instructional material they own into smaller pieces, then reassembling it to construct lessons or courses in a more desirable way, that serves better their instructional goals [5]. Adapted to the environment that is shaped by multimedia computers and broadband Internet connections the concept is that future courses will be created by combining reusable LO, stored in databases. These special databases, called the Learning Objects Repositories (LOR) [6] are already a reality [7] [8].

Learning on Demand (LoD) is a natural outcome of the above situation. It is LoD that perfectly fits to modern adult-learning theories [9]. The notions “just in time”, “just enough” and “just for you” in learning are just-what-an-adult-learner-needs.

II. The Megaworld

An adult, as part of his/her learning effort, will be searching –exploring– the Repositories for proper Learning Objects. We call this situation *the Megaworld*, by analogy (and in contrast) to the Microworlds notion [10]. A Microworld is a small, but complete, version of some domain of interest; the Megaworld is huge, incomplete, chaotic, distributed, presenting various aspects of all domains of interest.

Aiming to set some order to this chaos, we assume that the Megaworld is divided into (a large number of) subspaces, we call them 1st degree subspaces. Each 1st degree subspace may also have subspaces, called the 2nd degree subspaces, and so on. For example, the Megaworld may contain as 1st degree subspaces the fields of Mathematics and Physics, while the latter may contain Kinematics, Waves, etc.

Every Learning Object added to the Megaworld also belongs to a subspace and has to be indexed in order to promote searching. This can be achieved by proper use of metadata. Metadata is information about information. Learning Objects Metadata (LOM) is defined as the attributes required to fully/adequately describe a Learning Object [11]. Metadata describe a LO in a manner that can be exploited by a specially designed educational search engine. For example one may use Nr 4 - Technical and Nr 5 - Educational fields of LOMv1.0 Base Schema in order to describe the content and other characteristics.

A special search engine therefore is needed. There are many reasons why search engines like Google are not enough for the purpose [12]. We will mention one more: a common search engine lacks Instructional Design. Instructional design models

Manuscript received March 4, 2006. IMECS 2006: International MultiConference of Engineers and Computer Scientists 2006, Hong Kong, 20-22 June, 2006.

G. Mavrommatis was with Department of Informatics, University of Piraeus, 185 34 Piraeus, Greece. He is now with the Hellenic Military Academy, Vari, 166 73, Attica, Greece (e-mail: gmav@unipi.gr).

(Advance online publication: 13 February 2007)

are strategies, based on learning theories. How can we incorporate instructional design principles into the Learning Object Repositories search procedures?

This paper aims towards this target. Remainder is organized as follows: In Section III, after adopting a working definition of Learning Objects, their properties are being studied and categorized, leading to a model that represents Learning Objects as members of an Information Space; in Section IV the model is connected with selected learning theories and information retrieval; finally some conclusions are drawn in section V.

III. A Definition, the Properties and a Model

In present paper we define Learning Object as "a standalone, reusable, digital resource that aims at teaching one or more instructional objectives or concepts" [13].

A Learning Object has a set of characteristics, we call them properties. These properties can be categorized into three clusters:

1) Content properties: a Learning Object, as already defined, presents (teaches) one or more objectives, skills or concepts. All the available Learning Objects, regardless of the educational field they are dealing with, compose the Megaworld, a huge, multidimensional Information Space.

2) Quantitative properties: any property that can be somehow measured and expressed by a number. Examples are size, download time, expected studying time, level of difficulty, number of content properties, etc. This cluster contains every property that can be reasonably presented by a number from a numeric scale –in other words, a cost.

3) Qualitative properties: all non-quantitative properties belong here. Examples include the type of instruction (lecture, case study, etc), the media the LO utilizes (graphic, video, text, audio, java program, etc), the setup of the webpage (style, colors, fonts, etc).

In order to represent Learning Objects in a uniform way as members of the Megaworld, a Vector Space Model [14] was chosen. This was done for the following reasons:

--It is relatively simple and can be easily implemented, as a general model -basis for creating adaptive e-courses- should be.

--It is based on well-known and widely used concepts.

--Strong information manipulation and retrieval techniques can be applied to it [15].

--Other more complicated models (e.g. vector weighted model) can be reduced to it.

The learning hierarchy [16] is a central idea in Gagne's theory. In order to plan instruction one must first identify a specific learning objective and construct a learning hierarchy for that objective. This learning hierarchy also determines the prerequisites for a given learning objective.

We assume, therefore, that every knowledge field or complex cognitive skill to be taught consists of a number of elementary skills. By using methods like Principled Skill Decomposition [17] or Task Analysis [18] the complex item can be broken down into constituent skills, which compose the m-dimensional Information (Sub-) space:

$$F = \{f_1, f_2, .., f_i, .., f_m\}$$

Let L be the pool (set) of Learning Objects containing teaching approaches to a certain knowledge field. Every $\lambda \in L$ can be characterized by a couple of vectors:

-- a *Content* vector, indicating the skills/concepts it presents:

$$\kappa = (\kappa_1, \kappa_2, ..., \kappa_i, ..., \kappa_m) \in \{0,1\}^m$$

where

$$\kappa_i = \begin{cases} 1, \text{ if object } \lambda \text{ teaches skill } f_i \\ 0, \text{ otherwise} \end{cases}$$

-- a *Usage* vector, indicating the skills/concepts it uses without previously teaching/presenting:

$$\mu = (\mu_1, \mu_2, ..., \mu_i, ..., \mu_m) \in \{0,1\}^m$$

where

$$\mu_i = \begin{cases} 1, \text{ if object } \lambda \text{ uses skill } f_i \\ 0, \text{ otherwise} \end{cases}$$

Obviously, a learner can also be represented by a similar 0-1 vector $u \in \{0,1\}^m$ expressing user's knowledge on the certain field:

$$u = (u_1, u_2, ..., u_i, ...u_m)$$

where

$$u_i = \begin{cases} 1, \text{ if user masters skill } f_i \\ 0, \text{ otherwise} \end{cases}$$

Having defined the model, the question that now rises is how can it be used to incorporate the learning theories and instructional design into the Learning Objects Repositories search procedure (Fig. 1). Next Section presents a few selected examples of such an implementation.

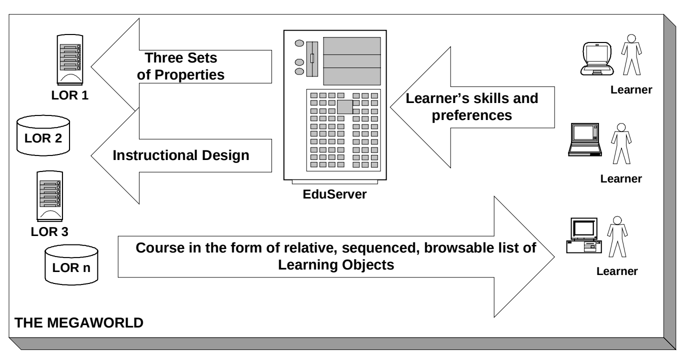

Fig. 1. Exploring the Megawolrd.

IV. Designing Automatic Instruction

The model described in section III will be used to support instructional design in course creation based on Learning Objects and Information Retrieval techniques. Four selected paradigms follow:

A. Cumulative Learning Theory and the Learning Hierarchy

According to Gagne's theory the lower-level tasks must be mastered before higher-level tasks. Therefore, in order to create the course, one has to sequence the proper Learning Objects, with respect to the Learning Hierarchy. For simplicity reasons, we assume that Learning Hierarchy is a tree of height h (Fig. 2). The tree has $h+1$ levels numbered from 0 (root node, the final objective) to h (leaves). Let $level(\theta)$ denote the level of each node θ.

Learning Objects selection and sequencing is accomplished as follows: starting from level h, we select $\lambda \in L$ such that the properties they present are not these the Learner already knows and are all at level h:

$$\kappa_i = 1 \wedge u_i \neq 1 \wedge level(\kappa_i) >= h$$

This is done repeatedly until the selected LO present all properties of level h that the Learner needs to learn. Then we set $h = h - 1$ and repeat the same procedure. We stop when $h < 0$.

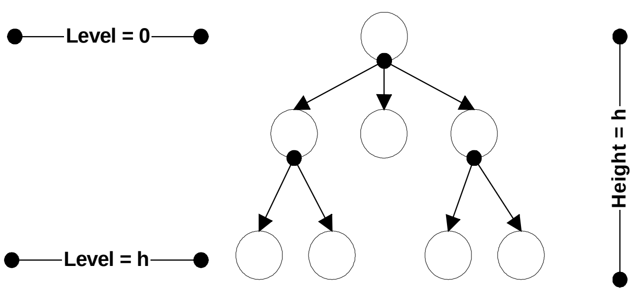

Fig. 2. Sample Task Analysis Outcome.

B. Subsumption Theory

Subsumption theory [19], proposed by Ausubel, uses Advance Organizers as its major instructional mechanism. An Advance Organizer is an instructional unit presented to the learner before the "main" instruction takes place. The method is used in order to link old, already known, information with the new concepts that are about to be taught. The Advance Organizer is more abstract than the information presented later, and has many different types.

A Learning Object $\lambda \in L$ that is selected to serve as Advance Organizer must have the following properties:

Content: use exactly the Content properties that the learner already masters, present the final objective (level 0 content property) and, possibly, a few level 1 properties:

$$\forall i : \mu_i = 1 \Rightarrow u_i = 1$$

$$\exists i_0 : \kappa_{i_0} = 1 \wedge level(\kappa_{i_0}) = 0$$

$$\forall i : \kappa_i = 1 \Rightarrow level(\kappa_i) \leq 1$$

Quantitative: it must be of small size, small required studying time, easily understood, low level difficulty, etc :

λ.Quantitative.Size ≦ LimitA

λ.Quantitative.StudyTime ≦ LimitB

λ.Quantitative.Difficulty ≦ LimitC, and so on.

Qualitative: depending on the different types of Advance Organizers, the Learning Object must be a case study, a story, an example etc, using video pictures or graphs and so on:

λ.Qualitative.Instruction=CaseStudy

λ.Qualitative.Media[1]=Graph

λ.Qualitative.Media[2]=JavaScript

λ.Qualitative.Type=Skimming

λ.Qualitative.Action=WhatIfAnalysis, etc

C. Elaboration Theory

Extending in various ways the Subsumption theory, Elaboration Theory [20] was proposed by Reigeluth in the late 70's. Among the major strategies proposed, elaborative sequence is the fundamental principle: the simplest version of the task (the "epitome") has to be taught first. Epitome should contain a few of the most basic ideas at a tangible, practical level. Instruction should be organized in increasing order of complexity.

Learning Objects selection and sequencing procedure first starts will the level 0 property and selects LO $\lambda \in L$ that present it. Then adds level 1 properties and selects again the proper LO. At each iteration minimum (preferably zero) involving of all the lower level properties must be ensured. Additionally, at each iteration the difficulty of the Lessons has to be increasing, possibly together with the size and required studying time:

1 Set LimitA≦λ.Quantitative.Size ≦ LimitAA

2 Set LimitB≦ λ.Quantitative.StudyTime ≦ LimitBB

3 Set LimitC ≦λ.Quantitative.Difficulty ≦ LimitCC

4 x = 0

5 LVL={x}

6 Select $\lambda \in L$ such that

- **6.1** $\forall i : \kappa_i = 1 \Rightarrow u_i \neq 1$
- **6.2** $\exists i_0 : \kappa_{i_0} = 1 \wedge level(\kappa_{i_0}) \in \text{LVL}$
- **6.3** $\min \left| \{ i : \mu_i = 1 \} \right|$

7 Output selected LO

8 x = x+1

9 increase both up and down Limits

10 LVL = LVL ∪ {x}

11 if x <= h goto 6 else goto 12

12 end

D. Dual Coding Theory

Based on Cognitive Information Processing Theory, the Dual Coding theory [21] proposed by Paivio proposes that there are two cognitive subsystems, separate but interrelated, one verbal and the other visual. Both systems can function independently, but there are interconnections between them that allow dual coding of information. Information therefore, is much easier to retain and retrieve when dual-coded in both visual and verbal form. It is Dual Coding Theory that offers the theoretical basis for the effects of graphics on learning.

Implementation in this case is straightforward. Learning Objects are selected in pairs $\lambda_1, \lambda_2 \in L$. Each pair has to present exactly the same content properties (Content vector) and use exactly the same skills (Usage vector). LO containing already known skills are excluded (or, at least, avoided). Within each pair (*λ_1, λ_2*) we demand that:

λ_1.Qualitative.Media=Text

λ_2.Qualitative.Media=Video or Sound

or

λ_1.Qualitative.Media=Speech

λ_2.Qualitative.Media=Graph, etc

Selected pairs may be presented either simultaneously or sequentially to the user.

V. THE BOTTOM LINE: CONSTRUCTIVISM

Based on the ideas of scholars like Dewey, Piaget, Vygotsky, Bruner, Papert, constructivism is considered the most popular Learning Theory today. Although it has not been described as a single instructional design model, it is clear that Constructivism believes in a recursive, non-directed, learner-centered instruction, with a more holistic, even chaotic approach [22]. Duffy and Jonassen in [23] state: "Viewed as an alternative perspective that includes a wide range of instructional strategies, constructivism is a pedagogical view that can be applied to most if not all learning goals.".

We believe that with the arrival of Learning Objects this target is coming closer to reality. This is the direction this paper is aiming to: by using a definition viewed mostly from an educational rather than technical aspect, three major groups of Learning Objects' properties were defined. Based on these properties, a vector space model was defined for presenting the LO. This mathematical model was used to implement a selected set of instructional design methods. The presented information retrieval techniques produce series of Learning Objects that are relevant to the Learner's needs, following instructional design methods and yet provide a context for learning that supports autonomy, exploration and relatedness, as Constructivism demands.

REFERENCES

[1] Eklund, J., Kay, M., and Lynch, H. e-learning: emerging issues and key trends. *Australian Flexible Learning Framework*, ISBN 1877057363, 2003.

[2] http://learnet.hku.hk/objects.htm
http://www.learnativity.com/standards.html
http://www.e-learningcentre.co.uk/eclipse/Resources/contentmgt.htm

[3] http://www.adlnet.org/

[4] Advanced Distributed Learning (ADL), *Sharable Content Object Reference Model* (SCORM®) 2004 Overview, 2004.

[5] Reigeluth, C. M. and Nelson, L. M., "A new paradigm of ISD?" In R. C. Branch & B.B. Minor (Eds.), *Educational media and technology yearbook*, Vol. 22, pp. 24-35, 1997.

[6] Muzio, J., Heins, T., and Mundell, R., Experiences with reusable E-learning objects. From theory to practice. *Internet and Higher Education* 5, 21–34, 2002.

[7] Najjar, J., Ternier S., and Duval, E., User Behavior in Learning Objects Repositories: An Empirical Analysis, in *Proceedings of the ED-MEDIA 2004*, pp. 4373-4379, 2004.

[8] Long, P., "Learning Object Repositories, Digital Repositories, and the Reusable Life of Course Content." available: http://www.campus-technology.com/print.asp?ID=9258

[9] Fidishun, D., Andragogy and Technology: Integrating Adult Learning Theory As We Teach With Technology, in *Proceedings of Extending the Frontiers of Teaching and Learning: the Mid-South Instructional Technology Conference 2000*, Murfreesboro, TN April 9-11, 2000.

[10] Papert, S., Computer-based microworlds as incubators for powerful ideas. In R. Taylor (Ed.), *The computer in the school: Tutor, tool, tutee*, (pp. 203-210). New York: Teacher's College Press, 1981.

[11] IEEE Learning Technology Standards Committee, http://ltsc.ieee.org/wg12/

[12] The Academic ADL Co-Lab, Finding and Sharing eLearning Objects, available: http://www.academiccolab.org/resources/Finding_Sharing.pdf

[13] Mavrommatis, G., Learning Objects and Objectives towards Automatic Learning Construction, to appear in *European Journal of Operational Research*, 2006.

[14] Salton, G., & McGill, M.J., *Introduction to Modern Information Retrieval*, McGraw-Hill, 1983.

[15] Baeza-Yates, R., Ribeiro-Neto, B., Modern Information Retrieval. ACM Press, 1999.

[16] Gagné, R. M., Wager, W. W. & Briggs, L. J., Principles of instructional design (4th ed.), New York: Holt, Rinehart and Winston, 1992.

[17] van Merriënboer, J. J. G., Training complex cognitive skills: A four-component instructional design model for technical training, New Jersey: Englewood Cliffs, 1997.

[18] Merrill, P. F., Task analysis: An information processing approach, NSPI Journal, 15(2), 7-11, 1996.

[19] Ausubel, D., The Psychology of Meaningful Verbal Learning. New York: Grune & Stratton, 1963.

[20] Reigeluth, C, Elaborating the elaboration theory, Educational Technology Research & Development, 40(3), 80-86, 1992.

[21] Paivio, A., Dual coding theory: retrospect and current status. Canadian Journal of Psychology 45, 255-287, 1991.

[22] Tam, M., Constructivism, Instructional Design, and Technology: Implications for Transforming Distance Learning, Educational Technology & Society 3(2) 2000, ISSN 1436-4522.

[23] Duffy, T. & Jonassen, D. (1991). Constructivism: New implications for instructional technology?, Educational Technology, May 1991, 7-12.