CONSTRAINTS ON REUSABILITY OF LEARNING OBJECTS

Didactic Aspects of Modular e-Learning in Engineering Education

Michael May, Peter Munkebo Hussmann, Anne Skov Jensen
LearningLab DTU, Technical University of Denmark (DTU), Building 101, Kgs. Lyngby, Denmark

Helle Rootzén
Department of Informatics and Mathematical Modelling, DTU, Building 305, Kgs. Lyngby, Denmark

Steen Markvorsen, Karsten Schmidt, Kasper Skårhøj, Søren Enemark
Department of Mathematics, DTU, Building 303S, Kgs. Lyngby, Denmark

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Abstract: It is the aim of this paper to discuss some didactic constraints on the use and reuse of digital modular learning objects. Engineering education is used as the specific context of use with examples from courses in introductory electronics and mathematics. Digital multimedia and modular learning objects have been proclaimed as important elements in e-learning for a long time, and there are good reasons to believe in the benefits of interactive multimedia as well as flexible and modular learning objects. Nevertheless the use and reuse of learning objects on a large scale seems to be a slow success. Constraints on reuse arise from the nature of conceptual understanding in higher education and the functionality of learning objects within present technologies. We will need didactic as well as technical perspectives on learning objects in designing for understanding.

1 INTRODUCTION

In a general sense *learning objects* (LO) have been defined as “any entity, digital or non-digital, that may be used for learning, education or training”. This is the broad definition given in the IEEE Draft Standard for Learning Object Metadata (IEEE LOM, 2002). Conceptually it is appropriate to include non-digital artifacts and learning resources like books and laboratory equipment in the definition of learning objects, even though most discussion focus on digital media objects designed, stored, distributed and displayed with the use of modern information and communication technologies (ICT). As such learning objects are at the core of “e-learning”. E-learning is understood here in the broad sense of any use of ICT to support teaching and learning (and mainly for “blended learning” rather than distance education).

A surprising aspect of the above definition, especially in the context of the LOM standard, is that learning object *metadata* is not considered an integral part of the learning object. This can be seen as symptomatic because one of the problems facing the reuse of learning objects is the *missing or inadequate metadata descriptions* of resources to be found in digital media archives, i.e. Learning Object Repositories (LORs).

In the following the metadata problem and other problems *restraining the sharing of learning objects* will be considered, including (a) didactic issues in supporting conceptual learning of scientific content, (b) the pedagogical scenarios specifying how learning objects should be used.

2 THE TECHNICAL AND THE DIDACTIC PERSPECTIVE

Reuse of learning objects (LOs) outside their course

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of origin will require descriptions of the objects *as learning resources*, i.e. metadata descriptions of their intended use that is relevant from pedagogical and didactic points of view. This means that the bibliographic metadata (e.g. author, title, year of publication) required by library databases will not suffice for LORs. Effective search and retrieval of LOs from digital archives will have to take information about the educational contexts-of-use into account, e.g. information about the intended pedagogical scenario for which the LOs were originally designed as well as the learning objectives and the competence level associated with their use.

For a teacher in e.g. chemical engineering it will not be sufficient to know the title of a LO within a given topic, e.g. thermodynamics. If she for instance is looking for a *simulation to be used within a student exercise to visualize* (: the pedagogical scenario) *heat flow in a fluid* (: the topic), then LOs just *illustrating* heat flow through static images will not be relevant for the chosen learning scenario or didactic situation. Even interactive java applets within the topic might not be adequate, because they would typically support a limited form of *parameter variation* useful for physics teaching at a high school level, but not the *construction of models* of heat flow based on differential equations as needed in the context of chemical engineering education.

On top of these topical and pedagogical constraints imposed on the relevance and reusability of learning objects, there is an additional didactic problem with regard to the specific conception of thermodynamics within chemical engineering. Even though e.g. heat flow seems to be a coherent topic that could be used in a neutral and objective way to index a given learning object, it turns out that different branches of science and engineering conceptualize thermodynamics in different ways (Christiansen & Rump 2008). Heat flow as a topic is thus treated slightly different in thermodynamics *within physics* as compared to how it is “framed” *within mechanical engineering* or *within chemical engineering*. What counts as paradigmatic examples and good illustrations will consequently be different in these three disciplines although they could all nominally be described as a part of the topic of “heat flow in thermodynamics”.

Within the scientific community focusing on the design and use of Digital Libraries the problem of finding appropriate learning objects in LORs such as e.g. Merlot, the Multimedia Educational Resource for Online Learning and Teaching hosted at www.merlot.org, have been noted (Najjar et.al. 2005), but the *didactic and pedagogical problems of reusability is often confused and obscured by usability issues* of the interfaces designed for these archives. The problem of finding appropriate LOs is then turned into the secondary issue of how to support navigation in user interfaces. Important as these HCI design issues are they should not mask the underlying didactic problems of reusability.

There has been a similar trend in instructional design theories to focus on the technical issues of multimedia and LOs. The very idea of flexibility and reusability of digital learning resources have arisen in the context of advances in software engineering such as object oriented programming, the separation of content and layout with XML technologies, and the development of Content Management Systems (CMS) for web content (Schär 2006). The Learning Management Systems (LMS) that support blended learning in higher education, including access to LOs, are basically specialized versions of CMS.

Given the discussion so far we can conclude that we need extended metadata descriptions including e.g. information about pedagogical scenarios of use as an integral part of the digital learning objects in order to support search, retrieval and reuse.

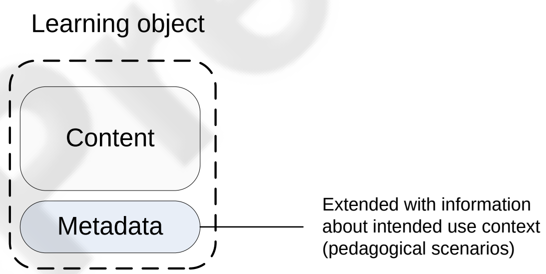

Figure 1: A (digital) learning object must include metadata as well as content.

Much work has been done on defining metadata standards to secure the *interoperability* of LOs, and with SCORM, i.e. the Sharable Content Object Reference Model, *reusability* is explicitly addressed as a functional requirement for the standard: “e-learning content designed for one organization can be redeployed, rearranged, repurposed, or rewritten by other organizations that have similar learning needs” (SCORM FAQ at www.adlnet.org).

This is however still a *technical perspective* on LOs. To introduce a genuine *didactic perspective* we will look at an example from a redesigned course in introductory electronics for students in computer science and engineering at the Technical University of Denmark (DTU).

3 LEARNING CIRCUIT THEORY

The example concerns the use of simple simulation and visualization tools in an introductory course in electronics. The introduction of these tools took place within a reorganization of course contents in order to enhance student learning and the flow of competences acquired through the progression of courses within a bachelor engineering program. This work was in itself a part of the CDIO educational framework (Conceive, Design, Implement, Operate) (www.cdio.org) for the development of engineering education (Crawley et.al. 2007).

In selecting simulation and visualization tools for student's learning of introductory electronics we found that different *dimensions of the media objects* (explained below) could be used to choose between the topically relevant learning objects based on the expected *cognitive support* for student learning relative to *didactic problems* found in learning the specific scientific content. We could, in other words, give specific arguments for the learning objects used rather than general arguments about e-learning.

One of the objectives of the redesigned course was to have students build a *conceptual bridge* between key concepts and components in *analogue* electronics (e.g. behavior of electrical circuits, resistance and capacitance) and key concepts and components in *digital* electronics (e.g. transistors and microprocessor circuits). This used to be difficult because analogue and digital electronics were taught in different courses without much coordination of the examples used.

3.1 Didactic Problems in Learning Electricity and Electronics

Another problem is that students have diverse prior knowledge in mathematics and physics, and there are *well known didactic problems in learning electricity and electronics*, some of which concerns the *conceptual understanding of electricity and circuit behavior* (May et.al. 2008):

(a) *Conceptual transfer problems* in using prior knowledge and skills in mathematics in introductory electronics (Waks 1988) as well as in applying basic knowledge of electricity to problems in electronics.

(b) *Dissociation of computational skills from model comprehension*. It is a general problem in science and engineering education that the ability of students to perform calculations does not necessarily indicate a deeper understanding of the theories and models they use. In electronics students develop skills for recognizing and solving standard problems of electrical circuits without considering the functional relations of the circuits. They can solve equations given a set of values by using simple laws (like Ohm's law and Kirchhoff's laws) but can not always explain the properties and behavior of electrical circuits in a qualitative manner.

(c) *Confusion of cause and effect* in learning about electricity and electronics in the sense that students have a tendency to focus on electrical *current* rather than on *voltage* (Cohen, Eylon, & Ganiel 1983). This is sometimes called the "battery-centred" model of electricity, since batteries are seen as the sole sources and agents of flows in simple circuits (Steinberg 1985). Unfortunately this conceptual problem can by worsened by the use of *analogies* that are otherwise supposed to enhance mental models of electrical flow, i.e. by analogy to fluid flow (Dupin & Johsua 1989). The water models of electricity give rise to misconceptions about electricity since they tend to focus students on localized events at the expense of global properties of electrical circuits and simultaneous events.

(d) *Conceptual difficulties in considering global phenomena*. It is a general problem in science and engineering education that students have difficulties in *considering global phenomena and simultaneous changes in several variables.* In electricity, electromagnetism and electronics the problem is not just a problem of *visualization* in a narrow sense, but a problem of conceptualization of a link between *observed global effects* and *microscopic processes* implied by theoretical models e.g. movement of electrons (Thacker, Ganiel & Boys 1999).

3.2 Dimensions of Media Objects and their Cognitive Support for Learning

As we stated above the point of considering didactic problems in the context of LOs is to provide specific reasons for the relevance of pedagogical scenarios and their inclusion of digital learning objects, since students need different forms of *cognitive support* to overcome these problems and this can be found selectively in different dimensions of the media objects used in blended learning. This is a general hypothesis that can only be exemplified here.

A simple form of learning objects that have been promoted to support student learning in e.g. physics is *interactive* java applets, where simple physical models are *visualized* and *animated*. Students can explore the effects of *adjusting a limited set of parameters* in the models. In physics education these java applets are known as "Physlets" (Christian & Belloni 2004). A collection of java applets for science education can be found at www.falstad.com. As media objects these applets can be described through dimensions such as *interactive*, *animation* and *2D visualization*. In introductory electronics interactive applets might play a role in establishing a *conceptual bridge* between analogue and digital electronics by supporting student's exploration of simple RC-circuits (i.e. circuits with a resistance and a capacitor), and the observation of graphs of current and voltage as functions of time as a capacitor is charged and decharged (Figure 1). The RC-circuit in *analogue* electronics is important for didactic reasons because students can observe that charging a capacitor takes time, and they learn that this delay (in principle) is responsible for the constraint imposed on the possible speed of computer chips in *digital* electronics (i.e. the clock frequency).

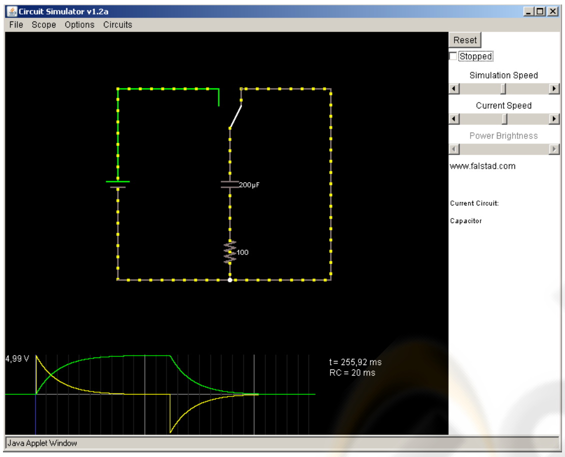

Figure 2: The Circuit Simulator java applet used to visualize the behavior of a simple RC-circuit. The graphs show current (yellow line) and voltage (green line) as a function of time (www.falstad.com).

Dimensions of media objects relevant for cognitive support for learning include (slightly revised from May et.al. 2008):

- Static visualization versus animation
- Spatial dimensionality (2-D, 3-D etc.)
- Mono-media versus multimedia
- Representational forms or "sign types" (e.g. images, maps, graphs, diagrams, language) (cf. May 2007, May & Petersen 2007)
- Linear versus hypermedia organization
- Supported user control and interaction forms (e.g. playback, simulation etc.)

Parameter variation is an important part of the exploration of models and the construction of mental models in science and engineering. The support for students to construct and simulate their own models is however quite limited in simple java applets. There are a number of other Open Source programs that can be used to construct and simulate electrical circuits such as "5spice" (www.5spice.com) and the Circuit Simulator (hosted at www.sourceforge.net).

In the present course the Circuit Simulator was used as a digital LO to build virtual circuits and test hypotheses about circuit behavior based on student's initial calculations and circuits sketches (Figure 2). Students were then instructed to construct selected circuits on breadboards, perform measurements and thus compare the virtual and the physical circuits. This way the LO was an integral part of a larger pedagogical scenario inspired by the *learning cycle* (Kolb 1984; Crawley et.al. 2007), according to which learning occurs in iterative phases of *abstract conceptualization* (e.g. students mental models and initial sketching), *active experimentation* (e.g. the virtual circuits), *concrete experience* (the physical construction and the measurements) and *reflective observation* (from virtual and physical circuits). This leads to the reconstruction of student's mental models (i.e. revision of the initial conceptualization).

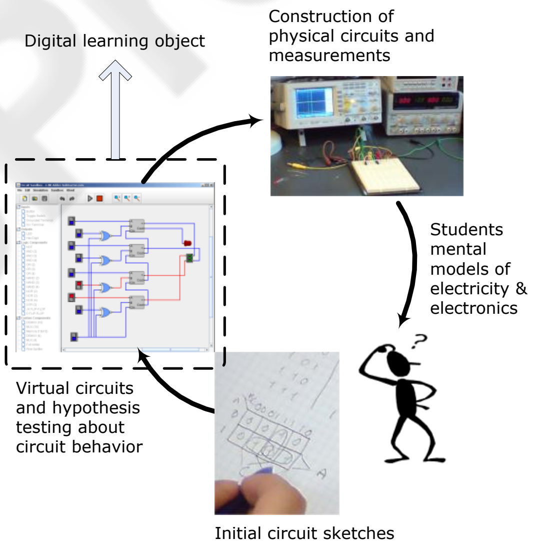

Figure 3: The Kolb learning circle for learning as applied to electrical circuit theory to show the didactic context of a digital learning object.

The learning cycle is however disrupted if the digital LO is abstracted from the pedagogical scenario in order to be reused in another context (Figure 2). This is an important counter-argument to reusability because experiments and hands on experiences in laboratories are seen as essential parts of engineering education. For students in engineering learning will often occur over longer periods of time as a topic is treated again in more advanced courses and concepts and models are seen from different perspectives or applied to physical constructions or experiments. *Learning should perhaps not be seen as an effect that can be encapsulated* within a single learning object or even within a single course, but rather as an extended process of conceptual change.

Virtual experiments and web-based instructions can be used to prepare students for lab work, but virtual labs can never be a complete replacement for physical experiments, because *virtual experiments are simulations* (cf. the “nomological machines” in science and engineering discussed in Christiansen & Rump 2006). Virtual labs do not offer (real) measurement errors and the learning experience of failure when experimental designs are flawed or theoretical assumptions refuted.

In learning about circuit theory in electronics students need several iterations of the elements of the Kolb circle: they need to make mistakes in sketching their own circuits, they need to explore interactively how different proposed circuits might work (as a form of thought experiments to be carried out through virtual circuits), and they need to build their own physical circuits and experience how real circuits behave and observe whether measurements correspond to the ideal conditions of the simulation. All elements are needed in order to promote conceptual change and the gradual construction of adequate mental models of e.g. circuit theory in electronics.

4 INSTRUCTIONAL DESIGN

As indicated above the tradition for research and development in Instructional Design is itself to some extend caught up in *the technical perspective on teaching and learning*. A good example is provided by one of the most advanced theories in Instructional Design, i.e. the theory of Instructional Components (Merrill 2001).

The theory of David Merrill can be seen as a kind of radical “object-oriented” approach to multimedia instruction. Learning and instruction is here assumed to be decomposable into small chunks of information (Schär 2006) much like the modular and flexible building blocks of a LEGO world (Wiley 2001).

An advanced aspect of this cognitively based theory of instructional design is its *semiotic* possibilities: modular objects of learning can perhaps be understood as the “words” of a *grammar of instruction* to be discovered. Just as layout and content is separated in modern XML based semantic technologies, we might be able to describe relevant *properties* as “affordances” of these multimedia components arising from combinations of features of the *media* (sound, graphics, haptics etc.) and features of the *representational forms* used (images, maps, graphs, diagrams, language), *both being distinct from the specific content expressed* (May 2007, May & Petersen 2007). Merrill suggests a series of pragmatic functions of instructional components, i.e. simple actions or “instructional transactions” like *showing, telling, asking and doing*. These are the kind of simple “actions” that human agents and artifacts engage in within learning and instruction, or rather *as seen from a technical perspective* on learning objects (instructional components).

There are however limits to this technical view. If we extend the LOs from small components to larger collections of components and includes strategies to support student learning (such as learning styles etc.) we will need to integrate these *threads of learning activities* within Learning Management Systems and support instructed navigation, and this threatens the idea of *modular* LOs. Flexibility of LOs can be realized, but not necessarily reusability and repurposing of modules.

5 LEARNING WITH E-MATH

Our second exemplification of learning objects concerns a course in introductory mathematics for engineers covering major topics in linear algebra, complex numbers and differential equations (fall semester), as well as Taylor series, integration, and topics in differential geometry (spring semester). The Computer Algebra System (CAS) *Maple* is well integrated in the course and Maple is used for computations and visualizations in lectures as well as in student exercises.

In the course given in fall 2009 a pilot project in e-learning called *e-math* had “taken oven” a particular week with the purpose of studying the *non-linear and individual forms of learning* made possible by a collection of web-based learning objects including *modular e-notes* covering the theoretical content (the content that would normally be presented in a linear way by textbooks and lectures), *Maple* demonstrations and exercises, *video appetizers* motivating and exemplifying topics, *video recorded lectures*, *interactive visualizations* in Maple and Geometer, and *multimedia pen casts* (recorded voice and drawing/writing) explaining particular methods. A related project for a "virtual mathematics learning environment" for engineering students have been described by (Vinuesa & Fornos, 2007), but the aim of this project has been to support distance learning rather than blended learning and without the focus on flexible learning objects.

The e-math prototype was developed in the open source Content Management System (CMS) *TYPO3*, the development of which was initiated by one of the authors.

A basic assumption of the e-math project is that *modular learning objects can be used for flexible teaching and learning by supporting individual differences in prior knowledge and skills and in approaches to learning ("learning styles")*. In the context of engineering education the learning styles suggested by the chemical engineer Richard Felder have gained some popularity. According to Felder individual learning styles can be identified through the answers to four questions (Felder & Brent 2005): Preferred type of information: *sensory* or *intuitive*? Most effective perception: *visual* or *verbal*? Preferred information process: *active* or *reflective*? Progress to understanding: *sequential* or *global*?

In the *e-math prototype* tested in the first week of November 2009 we included an option for students to select a particular learning style (using a slightly different typology) in browsing the learning objects for the topics of the week. Selecting a learning style would simply *rearrange the recommended sequence of learning objects* (e.g. to watch an appetizer video on the topic before reading the theoretical e-note), but would not change the *obligatory core of learning objects* that students had to study. The e-math prototype was deliberately designed to contain "too much" learning resources in order to support individual exploration on different topics on different levels of detail. Some students found learning styles useful, whereas others ignored this option by following a generic order of objects.

Learning styles is a disputed concept and as Felder himself points out it can be misused if teaching is adapted individually to these styles, since students need to develop skills characteristic of each type of learner in order to function effectively as future engineers. The pedagogical concern should be to support *variation in teaching methods* and *variation in the presentation of content*.

The challenge raised by the *diversity of student's prior knowledge and skills* seems to be much more important to address in higher education and here adaptation based on online testing is more promising (Clark & Feldon 2005). Learning objects can play an important role in *harmonizing competence levels* of students and in providing individualized assistance for students with deficient prior knowledge in specific areas. At DTU the web-based e-math was used after the ordinary lectures in the time slots assigned for computational exercises and other assignments, but e-math was also used by students to prepare for lectures and as repetition.

The e-learning content of the e-math prototype was focused on a particular week for purely pragmatic reasons, but it is expected that more learning objects will be added. The week chosen has a significant role in the course as a whole: after the introduction of linear algebra and complex numbers in the previous weeks, the content of the selected week returns to the topic of differential equations that students know from high school mathematics, but now with the added learning objective of using linear algebra and complex numbers for exploring and solving 1. and 2. order differential equations.

Figure 4: The web interface of the e-math prototype (November 2009).

Student *navigation of the learning objects* in the test week of November 2009 was based on a selection of available topics and subtopics for the week (left column in figure 3). In the figure the subtopic "linearity and solution structure" have been selected, and this brings up a list of *activities contained in the learning object*, some of which are *obligatory* (an example to demonstrate the solution structure of a differential equation, a video recording of the lecture on the topic, and an assignment in solving equations with and without the use of Maple) and some of which are *optional* (in this case an e-note on linearity and solution structure, and a Livescribe SmartPen pencast that play through a written exercise with voice over explanation (figure 4).

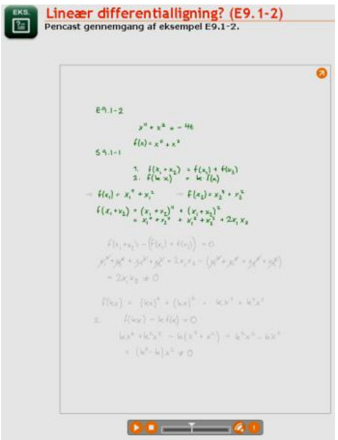

Figure 5: Multimedia pencast (flash animation) with animated writing, drawing and voice. The exercise is an optional activity contained in a learning object.

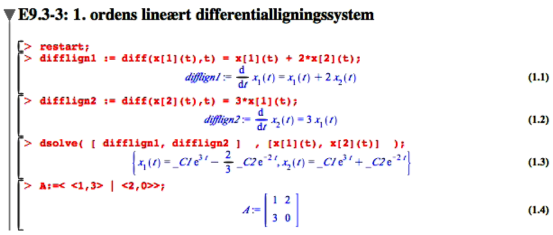

Figure 6: Screencast with voice over explaining an example in Maple syntax.

Maple examples included not only exercises where students should use Maple themselves, but also screencasts of worked out examples (with voice over explanations). Students found these video examples useful because they exemplified the Maple syntax in important areas where it is significantly different from the notation used in the e-notes (and the textbooks on which they are based).

Students were still expected to follow lectures even though they were also recorded and uploaded to e-math. Video lectures were mainly used for repetition, but in the future they could be used as replacements for some lectures (or parts of them), thereby liberating time for focused discussion with students on difficult topics and for the development and maintenance of e-math learning objects.

Video recorded interviews and lectures were however also used in e-math as *appetizers* for the different topics. These optional activities included lectures given at other departments in order to *exemplify the application* of differential equations in different domains of science and engineering, and thereby *motivate the topics*.

An example is show below where Ph.D. student Qiyuan Li (Department of Systems Biology, DTU) gives a lecture on biological modeling with differential equations (e.g. predator-prey systems).

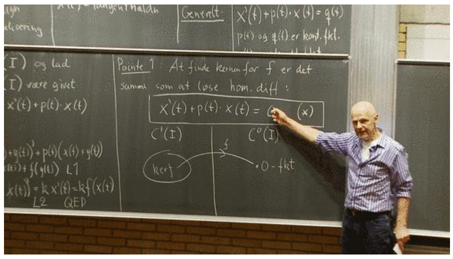

Figure 7: Karsten Schmidt giving a lecture recorded and uploaded to e-math.

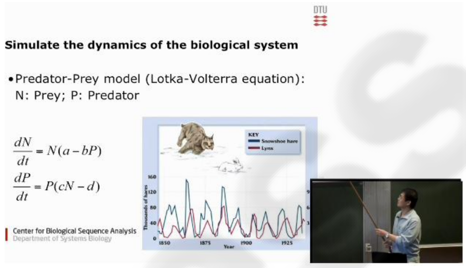

Figure 8: Screen shot from an e-math video lecture illustrating the application of differential equations.

Originally the e-math test should have included a *hypergraph navigation module* for supporting non-linear access to the learning objects, but for the limited time period of the test and the limited number of topics and corresponding learning objects and activities, the hypergraph would not be able to show its full potential. Interactive hypergraphs are used to visualize and navigate large tree structures and networks and they could be useful for non-linear navigation of topics, learning objects and their activities, but it should again be recalled that we should not only understand their design and use from the *technical perspective* (of the interface and its implementation), but also from the *didactic perspective* of the topical structure and the ways in which it might constrain learning.

6 CONCLUSIONS

In designing the e-math prototype it soon became clear that *student learning would need to be supported by recommended sequences of activities* (adapted to learning styles or not) since any non-guided exploratory use of the system, e.g. jumping between unrelated documents, would be confusing and counterproductive for the learning objectives of the course. This however once again (as in the case of the “learning cycle” for learning about circuit theory) points to the dilemmas and constraints imposed on the use and reuse of learning objects: if conceptual understanding of topics in e.g. engineering education require extended coherent sequences of learning activities, then the desired (“LEGO”-like, cf. Wiley 2001) modularity and flexibility of the components of instruction (Merrill 2001), does not necessarily entail that they can be reused “out of context” and repurposed within other scenarios and other organizations (cf. the ideal expressed by the LOM standard). Perhaps advances in semantic web technologies such as the use of ontologies, automated indexing, software agents and social tagging of content can render learning objects of the future more “intelligent” with regard to how content can be combined and recombined (McGreal 2004, Gašević et.al. 2007), but even with this kind of technical vision we cannot escape the necessity of considering the didactic perspective on learning and the constraints imposed on learning.

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