Knowledge-rich indexing of learning objects
Kabel, S.C.

Citation for published version (APA):

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2 Theoretical analysis of material handling processes

This chapter reviews literature relevant for the material handling processes: analysis, storage, retrieval and re-use. This chapter is partly based on the theoretical sections in two articles, published in the Journal of the American Society for Information Science and Technology (Kabel, de Hoog, Wielinga & Anjewierden 2004a), and in AACE Journal of Educational Multimedia and Hypermedia (Kabel, de Hoog, Wielinga & Anjewierden 2004b).

2.1 Introduction

As already noted in Chapter 1, the Internet is becoming an important source of e-learning material, which is evident from the steadily growing number of learning object repositories and an increasing market interest. To achieve widespread re-use of instructional material through the Internet, substantial effort has been put in standardizing metadata for digital (learning) resources (Dublin Core Metadata Element Set (DCMES), 2003; IEEE standard for Learning Object Metadata (LOM), 2002).

With this effort put in standardization, interoperability has improved and the basis to store and exchange material is set. To fully realize the opportunities available for distribution and re-use of the available resources, several problems must be resolved. Chapter 1 illustrated these problems. This chapter provides a theoretical framework of the material handling processes based on the literature and identifies several issues that are investigated further in this thesis. First an assumption is made about what types of material can be distinguished and about what constitutes a learning object in Section 2.2. This is followed by an argumentation for the kind of annotation structure and indexing vocabulary that is required to classify learning objects of varying grain sizes in Section 2.3. Section 2.4 reviews available annotation structures and indexing vocabularies. Sections 2.5 to 2.8 discuss approaches to solve problems with analysis, storage retrieval and re-use, followed by conclusions in Section 2.9.

2.2 Types of material

A range of different types of material is available for re-use: small pieces of material (soundtracks, video shots, images); Web pages; larger structures such as lessons and courses. Re-use basically means that creating the content in instructional material completely from scratch is avoided by repeatedly using available materials of a small grain size in different documents, lessons, courses etc., which in turn can be applied in a teaching or learning situation. For example, a teacher prepares a presentation in order to support some lecture. The teacher consults several sources looking for relevant material. Because large pieces of material do not fit in the presentation and it would take time to search within documents that might contain relevant material, the teacher needs fragments like sections, images and audio frag-
ments. The degree of re-usability of material of various grain sizes differs (small pieces of material are likely to be used repeatedly in different documents, lessons etc.). Therefore it is important to distinguish between the grain size material can take.

In the literature two streams of research define types of material of different grain sizes. One stream of research has led to standardization of annotation structures and indexing vocabularies for (instructional) material. Instructional design theory, a second, closely related stream of research focuses on how to create and use instructional material.

The stream of research concerned with standardization takes a broad view on “material”. The Dublin Core Metadata Element Set (DCMES) (2003), a standard not specifically geared towards instructional material, defines an “information resource” to be “anything that has identity”. DCMES does not define grain sizes for information resources. In the IEEE standard for Learning Object Metadata (LOM) (2002), learning objects are defined as “any entity, digital or non digital, that may be used for learning, education or training”. In the LOM standard, learning objects can vary in grain size from raw media data or fragments to a set of courses that can lead to a certificate. Similarly, in the European version of LOM, the ARIADNE Educational Metadata Recommendation (EMR) (2002), learning objects are described as pedagogic resources that can vary in grain size from a document to a course.

Several instructional design theories provide precise specifications of types of material with a small grain size.

With Instructional Transaction Theory (ITT), Merrill aimed to automate instructional design (Merrill, 1997). At the core of ITT are “knowledge objects” and “transaction shells”. A knowledge object is defined as consisting of a set of predefined elements, each of which is instantiated by way of a multimedia resource (text, audio, video, graphic) or a pointer to another knowledge object. Four kinds of knowledge objects are defined: entities (for example a person or a thing), activities (an action performed by a learner on an entity), processes (events that affect an entity often as a consequence of a learner activity) and properties (qualities or quantities associated with an entity, activity or process). A transaction shell consists of rules for selecting knowledge objects, including rules for dividing knowledge into “mind-size chunks”. An assumption of ITT is that a knowledge structure to be taught can be decoupled from the material used to teach it. This means that the information presented to the learner is only an element of a knowledge object and as such it can easily be replaced with similar material (text, audio, video, graphic) without affecting the remainder of the knowledge object.

In his Learning Object Design and Sequencing Theory (LODAS), Wiley (2000) defines a learning object as “any digital resource that can be re-used to support learning”. Wiley excludes large, undifferentiated source documents such as textbooks and manuals, from the definition of a learning object because they hamper re-usability and must be segmented first. Wiley defines 5 types of learning object of increasing grain size that are highly reusable. The most elementary type is the single-type (or fundamental) object, which is an individual digital resource uncombined with any other, for instance an image that serves as an example. The combined-intact type is a small number of fundamental objects that cannot easily be separated, such as a video that comprises image and sound. The third type is the combined-modifiable object, a larger number of (lower level) resources combined by a computer at real time when a request for the object is made, for instance a Web page comprising
text, an image and a video. The fourth and fifth types of learning object are defined as logic and structure for combining lower level objects. The generative-presentation object is for instance a presentation used in a lesson. The generative-instructional object also evaluates student interactions, for instance to support abstract instructional strategies (such as “remember a list, follow a procedure, classify, etc”) used to achieve a certain type of learning goal. This type can best be compared to an “instructional transaction shell” in ITT (Merrill, 1997). Wiley further provides guidelines (for humans) to specify larger instructional structures by sequencing learning objects.

The approach of Cisco Systems (2001) is partly based on Merrill’s Component Display Theory (CDT) (Merrill, 1983), the predecessor of ITT. Cisco Systems distinguishes Reusable Information Objects (RIO) from Reusable Learning Objects (RLO). A RIO consists of content, practice and assessment items, and an RLO consists of several RIOs, sandwiched between an overview and a summary. A RIO is labeled as concept, fact, procedure, process, or principle, the content types Merrill defined in CDT.

From the standards and instructional design theory it follows that material that can be used to learn from can be located on a continuum, as illustrated in Figure 2-1. At one end of this continuum are fragments of an informational nature that contain data, for example facts, to inform someone. As more instructional ingredients such as an advance organizer or a question are added to a piece of information, its size and structure increases and in parallel its instructional meaning.

In this thesis, a learning object is defined as any electronic piece of material that can be used or re-used in an instructional context. Any electronic piece of material can be located somewhere on a continuum from informational material to instructional material (see Figure 2-1). There is a trade off between grain size and re-usability. Small fragments (for instance a single image) can be used in many different contexts; they can be combined with many other fragments. Larger fragments (for example an image and accompanying text and audio) fit into fewer contexts than small fragments. The more instructional ingredients are
added to a fragment, the more its instructional nature increases and its re-usability decreases. For example, an instructional ingredient such as an advance organizer is added to some piece of information about some topic. The advance organizer as such has no meaning without the information fragment that it regards. Enhanced with the advance organizer, the fragment fits into fewer contexts than without the advance organizer. If fragments of a small grain size have a higher potential to be re-used than fragments of a large grain size, the question is: how elementary should fragments of a small grain size be? Wiley (1998) argues that the degree of re-usability is inversely proportional to the number of ideas, concepts, facts, or meanings represented in the fragment. His answer to the question how elementary the smallest fragments should be is: as small as possible with preservation of at most one concept represented in the fragment that retains meaning when isolated outside the original context. From a re-use perspective, informational material has a small grain size (fragment) and is likely to be re-used by designers to develop instructional material. Instructional material in general can have a small grain size of a fragment that includes instructional ingredients but can also have larger grain sizes up to a curriculum, and is likely to be used and/or re-used by teachers to teach and by learners to acquire knowledge.

The grain sizes of material distinguished in this thesis are based on a synthesis of grain sizes defined in LOM and EMR, shown in Table 2-1.

<table>
<thead>
<tr>
<th>LOM: Aggregation level</th>
<th>EMR: Granularity</th>
<th>This work: Grain size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1: Smallest level, for example raw media data or fragments</td>
<td>Document</td>
<td>Document fragment</td>
</tr>
<tr>
<td>Level 2: Collection of level 1 learning objects, for example a lesson</td>
<td>Session or lesson</td>
<td>Lesson</td>
</tr>
<tr>
<td>Level 3: Collection of level 2 learning objects, for example a course</td>
<td>Course or course template</td>
<td>Course</td>
</tr>
<tr>
<td>Level 4: Largest level, for example a set of courses that lead to a certificate</td>
<td>Curriculum</td>
<td></td>
</tr>
</tbody>
</table>

Table 2-1 Attributes and values for the grain size of material.

The smallest elements, document fragments that can result from segmentation, serve as elements to compose instructional material, which can ultimately result in the largest instructional structure, a curriculum. Larger pieces of instructional material are defined as collections of smaller elements. A curriculum consists of several courses; a course can comprise several lessons; lessons can make use of several documents; a document consists of fragments (chapters, sections, images) that together constitute a document.
2.3 Indexing framework

Given the diversity of material and a variety of information needs, an indexing framework for indexing material is essential to achieve flexible retrieval and wide-spread re-use of material. An indexing framework consists of an annotation structure and an indexing vocabulary. An annotation structure is defined as a collection of attributes, with possible attribute values specified in an indexing vocabulary.

An indexing framework can vary from an unorganized collection of terms associated with an object, to a complete datamodel of objects, attributes and relations used in combination with structured indexing vocabularies. The discussion about an indexing framework concentrates on four aspects. Two aspects regard the annotation structure: the scope of an annotation structure (which properties are represented in attributes and which are not?), and the amount of structure in a set of attributes (a linear list of attributes or a datamodel of objects, attributes and relations?). The degree of structure can also vary in an indexing vocabulary. Two aspects of the indexing vocabulary are a point of discussion: the amount of structure in an indexing vocabulary, and the degree to which indexing vocabulary is open or closed (whether arbitrary terms can be used in a vocabulary or a set of terms is predefined).

2.3.1 The scope of an annotation structure

One aspect of an indexing framework is the scope of an annotation structure. It must be decided which attributes are included. Possible relevant attributes to annotate material may be identified by asking three questions: what must be annotated, what is it about, and how can it be used? To enable retrieval and support re-use of material, the scope of an annotation structure should include physical aspects of the material itself (for example the medium type and way of representation), domain related aspects of the material (for example a topic and keywords), and task-aspects (for instance learning goal and instructional strategy). Physical aspects of the material itself and domain information are necessary to retrieve material, and task-related information is necessary to support re-use of retrieved material. Re-use tasks basically consist of creating instructional material and of using instructional material for example in a lesson. This will be elaborated in Section 2.8.

2.3.2 The degree of structure in a set of attributes

A second aspect of an indexing framework is the structure in a set of attributes. The degree of structure in a set of attributes can vary. For example a simple “bag of keywords” has no structure represented in attributes. A set of attributes can be organized in two ways: a linear list of attributes, or a datamodel of objects, attributes and relations.

In a linear list of attributes, relations cannot easily be expressed. Although attributes in a linear list can be grouped into categories (for instance the category of educational attributes in LOM), specifying a relation is only possible by identifying terms in attributes. For example, the elaboration of a subject in a document can be represented by nesting attributes in a tree structure, but an image about the same subject in a different document has to be linked via identification of that subject in an attribute. Unless all documentation used is structured very similarly, a deep-leveled tree structure is not widely applicable. To avoid deep-level nesting in an annotation structure, the relations in a tree structure can also be
represented by a part-of attribute, but that solution also requires identification of a term in an attribute.

This problem can be solved by specifying relations in a datamodel. Like in a linear structure, a relation is represented in an attribute, but the attribute value is not a term from a vocabulary but a placeholder for another annotation structure. An example of a structured datamodel is the annotation structure for photos of animals described by Schreiber, Dubbeldam, Wielemaker and Wielinga (2001). One of the attributes in this annotation structure is “subject matter description”. To specify this attribute, an annotation structure is defined consisting of attributes “agent”, “object”, and “action”, which for example can take the values “ape”, “eat”, “banana”. The attributes “agent” and “object” can in turn be refined with a set of attributes, for example “color”, which can take the value “orange”. This annotation structure illustrates the advantage of the possibility to express relations. For example, the notion of “a chimpanzee under large tree” can be expressed using this annotation structure. When no structure is represented in attributes, for instance in case of a set of keywords, “large” can refer to the chimpanzee, the tree, or even the photo.

2.3.3 The degree of structure in an indexing vocabulary

A third aspect of an indexing framework is the structure in the terms in an indexing vocabulary. An indexing vocabulary can be unstructured (flat), for example an unordered list of keywords or a value scale, or structured (a hierarchy of general and specific terms).

A lack of structure in an indexing vocabulary can be problematic when indexers and retrievers have different mental models, leading to inconsistent use of terms. Different viewpoints on a domain can lead to discrepancies in terminology of the indexer and the end user. An unstructured indexing vocabulary also has the disadvantage that different levels of abstraction cannot be expressed in an organized way. Hence, different expertise levels of indexer and end user can lead to terminology used at different abstraction levels. For example, a professor in biology may use the terminology of an expert, while biology students may not (yet) be familiar with those terms. Specification may be easier than abstraction (naming an example of a vehicle is easier than categorizing a car as a vehicle) only to some level (naming an example of a Renault car is, for non-experts, more difficult than classifying a Renault as a car). A structured indexing vocabulary has the advantage that different abstraction levels can be expressed in a hierarchy of terms. Structured vocabularies may help users to define their need for information more accurately than unstructured lists of terms. For instance, a person who is interested in some topic is often not yet in a position to specify precisely what is required (Belkin, 1980). A conceptual hierarchy of terms that reflect the topics in a domain may help this person to translate a need for information into the attribute values used for retrieval.

2.3.4 An open or a closed indexing vocabulary

Finally, a fourth aspect of an indexing framework regards the free inclusion of terms in an indexing vocabulary. An indexing vocabulary can be open or closed. An open indexing vocabulary is characterized by the ad hoc basis on which indexing terms are included. Terms are not specified in advance but instead they are included in a vocabulary at the time they become available. An example of an open vocabulary is the “bag of words” that can be the
result of keywords automatically derived from a document itself. Another example is a person who annotates a document using keywords that come to mind. The free inclusion of terms in an open indexing vocabulary is similar to the use of natural language. This has the advantage of flexibility and expressiveness in terms of the specific information that can be represented. At the same time natural language is ambiguous: a single term may have different meanings in different contexts. There may be discrepancies in terminology used in source documents, by indexers, and by end users. Hence, an open vocabulary can lead to a matching problem with retrieval. The use of natural language in open vocabularies does not allow for standardization, which is necessary to serve a wide variety of people. In a closed indexing vocabulary, the indexing terms are pre-defined, for example a fixed list of keywords.

2.3.5 An indexing framework based on ontologies

The “closed-vocabulary approach” to indexing has been based on the use of thesauri, but more recently on the use of thesauri enriched to ontologies. A thesaurus is a controlled vocabulary, generally with a hierarchical structure, using broader-narrower relationships. In addition associative relationships are used in thesauri, which are normally as simple as “term A is related to term B”. In ontologies, knowledge is represented in a more formal way, which allows expressing semantics in a structure of concepts, attributes and relations.

A body of formally represented knowledge necessary to index fragments is based on a conceptualization: an abstract, simplified view of the world that we wish to represent. Ontology, in the philosophical sense, is a theory about existence. Aristotle attempted to bring order in the process of categorization of things in the world by reasoning about discriminating properties. As Artificial Intelligence deals with reasoning about models of the world, it is not surprising that the term ontology is adopted to describe what can be represented of the world in a computer program. In Artificial Intelligence, an ontology is defined as a formal explicit specification of a shared conceptualization (Gruber, 1993). Studer, Benjamins and Fensel (1998) explain “conceptualization” as referring to an abstract model of some phenomenon in the world by having identified the relevant concepts of that phenomenon. “Explicit” means that the type of concepts used and the constraints on their use are explicitly defined. “Formal” refers to the fact that the ontology should be machine understandable, which excludes natural language. “Shared” reflects the notion that an ontology captures consensual knowledge, that is, it is not private to some individual but accepted by a group. A more mundane view is given by Berners-Lee, Hendler and Lassila (2001) who define an ontology as a document or a file that formally defines relations among terms. How loosely or strictly defined, the important point is that an ontology offers a shared and common understanding of some domain that can be communicated across people and computers.

The basic building blocks of an ontology are concepts, attributes and (is-a and/or part-of) relations. These building blocks are best explained by means of an example. A “car” is a concept; the “color” of a car is an attribute, with value “green”. A superconcept is the parent of a subconcept. A “vehicle” is-a “car”, and a “wheel” is part-of a “car”. Is-a relations allow for inheritance of attributes. An instance of “car” is a car with license plate “XY-12-PQ”.

Concepts in an ontology are associated with a number of terms representing synonyms and/or abbreviations. Different terms used in material or queries can be mapped onto a unique concept in the ontology. For instance, synonyms of a unique concept “car”, such as
“auto”, “motorcar”, “automobile”, are represented in an attribute of that concept. When searching for material about a car, any of the synonyms can be used in a query. This approach alleviates most of the problems associated with ambiguity of natural language, different mental models of indexers and retrievers and even different languages. To account for different levels of abstraction, each concept in an ontology is represented as a unique element in a hierarchical sub/super class structure. The sub/super hierarchy allows representing the generalization/specialization relation, so that general queries result in the retrieval of general and specific objects (for example, a query for vehicles also results in cars) and oppositely specific queries result in the retrieval of specific and general objects (a query for cars also results in vehicles). Rosch (1976) defines natural categories at a level of abstraction at which one can obtain the most information with the least cognitive effort. The use of natural categories is stimulated through structuring some domain into general and specific concepts so that query expansion and specialization is supported.

The expectation is that using ontologies as a basis for an indexing framework has several potential advantages. A closed vocabulary allows for standardization and yields precise search results. A structured indexing vocabulary allows for precise use of terms, supporting consistent indexing and flexible retrieval, and also has a high potential to yield precise search results. Ontologies allow for a rich expression of physical aspects of the material, the domain the material is about, and the task that is carried out with the material. By using ontologies for indexing purposes, the expressiveness of natural language can be approached, which is necessary to be able to express the meaning of a fragment, and at the same time standardization can be achieved.

2.4 Available annotation structures and indexing vocabularies

Several standardized annotation structures are available for indexing and retrieval of (instructional) material. The Dublin Core Metadata Element Set (DCMES) (2003) is the standard for “information resources”. The IEEE standard for Learning Object Metadata (LOM) (2002) is the standard for the classification of instructional material. Several organizations contributed to LOM, and are closely related to LOM. The ARIADNE Educational Metadata Recommendation (EMR) (2002) can be seen as the European counterpart of LOM, geared towards the European educational system and supporting several different European languages. Instructional Management Systems (IMS) can be seen as development-oriented and provides among other annotation structures the Learning Resource Meta-Data Information Model (2001). The Sharable Content Object Reference Model (SCORM) (2001) of the Advanced Distributed Learning initiative (ADL) is a widely used implementation-oriented version of LOM.

The DCMES is a basic annotation structure to classify electronic material, comprising 15 general attributes. It is widely used as a standard annotation structure for information resources but not specific for instructional material. The standard for instructional material, LOM, groups a much larger number of attributes into 9 categories, and EMR specifies 7 categories of attributes. Table 2-2 compares the three annotation structures.
Most (categories of) attributes are explained by their name; some are explained below. In DCMES, the Coverage attribute stands for a place or time period the material is about. Format is explained as “the physical or digital manifestation of the resource”, and the Resource type attribute is explained as “the nature or genre of the content of the resource”. Relation allows specifying a reference to a related resource. All attributes in DCMES are also represented in the categories of attributes in the other two annotation structures. The Lifecycle category in LOM groups information about the history, current state and contributors to the material. The Meta-metadata categories in LOM and EMR provide information about the annotation itself, for instance who created it. Comments that allow assessing the educational use of material can be expressed in Annotation categories. A particular (domain-specific) classification system can be used in the attribute Subject, respectively the categories Classification and Semantics of the resource.

The difference between DCMES, which is designed for resources in general, and the other two annotation structures that are designed for learning resources, is most evident from the educational annotation structures in LOM and EMR. Whereas DCMES specifies only the type of resource, LOM and EMR contain several additional attributes for educational aspects. The annotation structures for educational aspects of material in LOM and EMR are compared in Table 2-3.

<table>
<thead>
<tr>
<th>DCMES attributes</th>
<th>LOM categories of attributes</th>
<th>EMR categories of attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title, Description, Identifier, Language, Coverage</td>
<td>General</td>
<td>General information on the resource itself</td>
</tr>
<tr>
<td>Creator, Publisher, Contributor, Date, Source</td>
<td>Lifecycle</td>
<td></td>
</tr>
<tr>
<td>Format</td>
<td>Technical</td>
<td>Technical characteristics</td>
</tr>
<tr>
<td>Resource Type</td>
<td>Educational</td>
<td>Pedagogical attributes</td>
</tr>
<tr>
<td>Rights</td>
<td>Rights</td>
<td>Conditions for use</td>
</tr>
<tr>
<td>Relation</td>
<td>Relation</td>
<td></td>
</tr>
<tr>
<td>Subject</td>
<td>Classification</td>
<td>Semantics of the resource</td>
</tr>
</tbody>
</table>

Table 2-2 DCMES, LOM and EMR annotation structures.
<table>
<thead>
<tr>
<th>Attributes in LOM Educational category</th>
<th>Attributes in EMR Pedagogical category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interactivity Type</td>
<td>Document Type</td>
</tr>
<tr>
<td>Learning Resource Type</td>
<td>Document Format</td>
</tr>
<tr>
<td>Interactivity Level</td>
<td>Interactivity Level</td>
</tr>
<tr>
<td>Semantic Density</td>
<td>Semantic Density</td>
</tr>
<tr>
<td>Intended End User Role</td>
<td>End User Type</td>
</tr>
<tr>
<td>Context</td>
<td>Context</td>
</tr>
<tr>
<td>Typical Age Range</td>
<td>Level</td>
</tr>
<tr>
<td>Difficulty</td>
<td>Difficulty Level</td>
</tr>
<tr>
<td>Typical Learning Time</td>
<td>Pedagogical Duration</td>
</tr>
<tr>
<td>Language</td>
<td>Country</td>
</tr>
<tr>
<td>(General category): Aggregation Level</td>
<td>Granularity</td>
</tr>
</tbody>
</table>

Table 2-3 Educational/pedagogical attributes in LOM and EMR.

Interactivity Type and Document Type refer to whether the material can be manipulated or is only for presentational purposes. This attribute can be refined with the attribute Interactivity Level: the degree of interactivity. Semantic Density stands for the degree of conciseness. Intended End User Role and End User Type allow specifying the user for which a learning object was designed. Context refers to the environment in which a learning object is used, for instance higher education. Typical Age Range and Level indicate the age, respectively the year of education of the intended learner. Difficulty (Level) expresses how hard it is to work through a learning object for the typical intended target audience. Typical Learning Time and Pedagogical Duration allow specifying the time it takes to work through a learning resource. Language and Country refer to the language of the intended learner and, respectively, the (European) country for which the resource was developed. The attributes Aggregation Level (in LOM located in the General category) and Granularity allow specifying the grain size of material (attribute values are shown in Table 2-1).

The possible values that can be assigned to these attributes are specified in a "value space" (a set of permitted values for an attribute), typically in the form of a closed vocabulary or a reference to another standard. In LOM and similar annotation structures, the possible attribute values for the semantic attributes (such as those in the educational category) are flat lists of terms. Because a standard is designed to be used by people all over the world, vocabularies are defined that everybody understands: mostly rather general, flat lists of terms. Examples of terms from indexing vocabularies defined for attributes in the LOM Educational category are given in Table 2-4.
<table>
<thead>
<tr>
<th>Attributes in LOM Educational category</th>
<th>Example values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interactivity Type</td>
<td>Active, Expositive, Mixed</td>
</tr>
<tr>
<td>Learning Resource Type</td>
<td>Exercise, Simulation, Questionnaire</td>
</tr>
<tr>
<td>Interactivity Level</td>
<td>Very Low, Low, Medium</td>
</tr>
<tr>
<td>Semantic Density</td>
<td>Very Low, Low, Medium</td>
</tr>
<tr>
<td>Intended End User Role</td>
<td>Teacher, Author, Learner</td>
</tr>
<tr>
<td>Context</td>
<td>School, Higher Education, Training</td>
</tr>
<tr>
<td>Typical Age Range</td>
<td>12-14 years old</td>
</tr>
<tr>
<td>Difficulty</td>
<td>Medium, Difficult, Very Difficult</td>
</tr>
<tr>
<td>Typical Learning Time</td>
<td>1 Hour</td>
</tr>
<tr>
<td>Language</td>
<td>English</td>
</tr>
<tr>
<td>(General category): Aggregation Level</td>
<td>(see Table 2-1)</td>
</tr>
</tbody>
</table>

Table 2-4 Examples of values for attributes in LOM Educational category.

This annotation structure allows classifying available instructional material, but (intentionally) does not express the level of detail necessary for designers to retrieve the information fragments they use to create that instructional material. A standard annotation structure such as LOM enables teachers and learners to exchange instructional material based on container descriptions rather than content descriptions. For instance, “Intended End User Role = Teacher”, although useful for retrieval purposes, provides no information on the content of the material.

For different types of material often different metadata is relevant. To give an example, the typical learning time is relevant information for a course, but a fragment like a paragraph of text or a single image requires information about the content: a topic, and other, more detailed semantic descriptions. Only if material is provided with adequate metadata at this lowest level of granularity, it is likely to be re-used in a meaningful way.

There are several vocabularies available that can be used to classify fragments. Table 2-5 compares attribute values for Resource Type defined in DCMES, Learning Resource Type in LOM, and Document Format in EMR.
<table>
<thead>
<tr>
<th>DCMESS Resource Type attribute, values</th>
<th>LOM Learning Resource Type attribute, values</th>
<th>EMR Document Format attribute, example values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collection, Dataset, Event, Image, Interactive resource, Service, Software, Sound, Text, Physical object, Still image, and Moving image.</td>
<td>Exercise, Simulation, Questionnaire, Diagram, Figure, Graph, Index, Slide, Table, Narrative text, Exam, Experiment, Problem statement, Self-assessment and Lecture.</td>
<td>Hypertext, Video, Exercise, Simulation, and Questionnaire.</td>
</tr>
</tbody>
</table>

Table 2-5 Attribute values for Resource Type in DCMESS and Learning Resource Type in LOM and EMR.

DCMESS further gives examples of Resource Types, for instance of types of texts: books, letters, dissertations, poems, newspaper, articles, and archives of mailing lists. However, the diversity of different value lists and the diversity of different dimensions addressed within value lists, indicates that a standard vocabulary for the more elementary learning objects, fragments, is desirable but not yet achieved.

To support designers and developers (who typically use information fragments to build instructional material), Wiley (2000) specified a domain independent taxonomy for inter-object comparison. This taxonomy allows a designer/developer to relate objects to each other, for instance in attributes “Potential for inter-contextual re-use” and “Potential for intra-contextual re-use”, with value scales like Low, Medium and High. Cisco Systems (2001) uses a vocabulary to describe the possible role of a fragment in instruction. Cisco System’s approach is to annotate an information object as Concept, Fact, Procedure, Process, or Principle (based on Merrill’s Component Display Theory; Merrill, 1983). This comes closer to the pragmatically oriented vocabulary designers need to retrieve material that forms the basis of their product.

In addition to available standards for learning objects, different communities of practice develop domain-specific indexing vocabularies. LOM allows specifying domain-specific hierarchies of terms in attribute Taxon Path, and EMR has several attributes to account for domain information, for instance Discipline, Sub-discipline, and Main Concept. For many domains however, there is no need to develop a domain ontology from scratch. In the context of the Semantic Web the content in Web pages is given well-defined meaning and structure by means of lexicons based on domain ontologies, and mapping schemas can be defined to integrate different domain ontologies (for example, Reed & Lenat, 2002).

To conclude the above discussion, there are several annotation structures and indexing vocabularies available to classify instructional material, but the more elementary learning objects may require additional, more detailed semantic vocabularies to support their re-use by developers. Standard annotation structures for informational and instructional material are linear lists of attributes (possibly grouped into categories). Where possible the permitted attribute values are specified in closed indexing vocabularies, generally flat lists of terms.
Current standards for instructional material lack the knowledge-rich and many faceted aspects that are needed to optimize re-use of information fragments through the Internet. This is intentional; the standards leave room for additional and customized metadata. A knowledge-rich indexing structure for the more elementary learning objects, for instance a paragraph of text or a single image, may help developers of learning material to retrieve these fragments more easily. As Polsani (2003) points out: “It is important that the developers agree on a set of specifications for development of learning objects covering such areas as technology, editorial requirements, and stylistic considerations. A commonly agreed standard will enable genuinely sharable and reusable content objects.” Mohan and Greer (2003) essentially stress the same issue: “There is yet no standard way to specify content in a learning object using XML. And the problem does not end with a set of commonly understood content tags. Content for different domains will need different markup tags”. The use of ontologies as a basis for an indexing framework is expected to provide elementary fragments of material with the necessary additional semantic metadata. An annotation structure and indexing vocabulary play a central role in the processes underlying the handling of material for re-use purposes. To approach problems that occur at each separate process, from analysis to re-using material, various research areas are relevant, which will be reviewed in the following sections.

2.5 The analysis process

Material comes in various grain sizes. To optimize re-usability, the fragments that make up larger pieces of material must be retrievable, so that they can be re-used in diverse instructional context. For instance, an entire encyclopedia is unlikely to be re-used in diverse instructional contexts. A single section in that encyclopedia about a certain topic, is more likely to be re-used in various contexts. Therefore, in many domains source material that in principle could form the basis of instructional material is analyzed and segmented into fragments. Segmentation requires a decision about the grain size of the resulting fragments. Because the interest is in optimizing re-usability, the focus is on digital learning objects of the most elementary type: fragments. Fragments are atomic; they consist of one, inseparable piece of material, for instance a short video, an image, or a paragraph of text. The nature of the source material (see Figure 2-2) must also be considered. Depending on the nature of the source material, fragments that result from segmentation can be categorized as informational or instructional (and located on the continuum in Figure 2-1).
If for example a reference work, designed for an expert to look things up, is carved up into fragments, the resulting fragments will have an informational rather than instructional nature. Segmentation of a pedagogical source document such as a geography textbook, on the other hand, will generally lead to fragments that contain not only information but also the instructional ingredients accompanying that information, for example an image accompanied by a textual explanation.

Thus, depending on the informational or instructional nature of the source material, fragments of different granularity should be identified. Segmentation of informational source material will generally result in smaller informational fragments than segmentation of instructional material.

Detecting fragments in a document can be done manually and to some degree automatically. In either way, fragments with coherent topics must be identified. The specific domain the material is about is therefore a crucial guidance for segmentation. The ideas expressed in material are often reflected in the structure of a document, for example topics are treated in paragraphs and aggregated into sections. The human eye can easily detect document fragments. For manual segmentation, for instance ARIADNE provides a tool, the Pedagogic Hypertext Generator⁴, which allows segmenting source material manually and by doing so create conceptual domain mark-up of HTML documents.

Automatic detection of fragments in a document is far from trivial. For automatic segmentation, three types of structures in documents are of importance: the layout structure, the logical structure and the semantic structure. In terms of layout, a document is structured

according to its physical components (text, image, line, rectangle, curve etc.), and visual representation expressed in geometry markup (for example, area, position) and formatting markup (font face, font size, color, line width etc.). The logical structure refers to the hierarchical organization of components in a document (for example, heading, section, paragraph). The semantic structure identifies the meaning of the hierarchical logical components (for instance, introduction, abstract). The structures are interrelated: the logical structure of a document consists of a part-of hierarchy of segments of the document, each of which corresponds to a visually distinguished semantic component of the document. (Anjewierden & Kabel, 2001; Summers, 1995). Figure 2-3 shows the three types of structures in a document.

![Figure 2-3 Document structures.](image)

Automated document analysis techniques are used to discover the logical document structure from the layout structure. Observed layout information is analyzed to determine the logical structure that was expressed in the layout. Thereafter the logical structure is processed in ways that differ per domain. Document analysis mainly considers geometry and layout to discover the logical document structure, whereas particular applications will also take into account the meaning of the text or image. Reasoning about the meaning is normally not necessary to discover the logical structure but is obviously necessary for manual segmentation and indexing.

It is expected that the use of ontologies can solve several of the problems in the analysis process. A domain ontology, by providing a hierarchically structured conceptual representation of a domain, can support manual or automatic detection of coherent fragments in a document. Concepts represented in a domain ontology may also occur for example in headings in the source material. In addition, document structures can be represented in ontologies serving as a knowledge base that can be used for automatic detection of fragments.

2.6 The storage process

Learning objects and their associated metadata are typically stored in distributed learning object repositories. Different repositories often use customized annotation structures, which leads to problems with exchanging material.

Repositories can differ from each other in several respects. First, to some repositories anyone can contribute material, others are not public or provide authorized access. A repository that is open for contributions has the obvious advantage of (often freely) available resources to anybody. Open repositories allow material to evolve: people can adapt or improve material
and store the result. But this approach also makes it difficult to control the versions and quality of material. Second, different learning object repositories can address different needs. Some repositories contain mostly courses for teachers; others contain mainly fragments for developers. For instance, Multimedia Educational Resource for Learning and Online Teaching (MERLOT) is a repository with material specific for higher education, and Science Math Engineering and Technology Education (SMETE) contains only material about several related disciplines. Because of this, subsets of different annotation structures may be selected to index the material, possibly in addition to customized annotation structures specific for some domain. The result is that different repositories use different and adapted annotation structures; therefore the attributes and possible values must be mapped onto a standard. An example of a mapping between annotation structures of EMR and LOM is described by Najjar, Duval, Ternier and Neven (2003).

Domain specific indexing vocabularies used in addition to standards can be highly structured representations of a domain. To achieve semantic interoperability, metadata representation languages such as XML and RDF are used. The use of ontologies may contribute to solving problems with the mapping of annotation structures, because these especially allow for conceptual representations of a domain in an indexing vocabulary.

2.7 The retrieval process

In the context of re-use through the Internet one should take into account a wide variety of people wanting to retrieve a wide variety of fragments for many different instructional goals and tasks. The problems that come with a free text indexing vocabulary, namely a lack of standardization and structure, result in a matching problem with respect to retrieval. Roughly two movements or paradigms can be discerned in research on information retrieval, a generic one focusing on improving information retrieval through automatic indexing and statistical methods, the other on controlled vocabularies, coming from traditional library and cataloguing studies. The stream of research focusing on generic solutions led to several ways to derive a set of keywords from a document (Spark Jones, 1999), different ways to determine the relevance of documents from term frequencies (Salton, 1977; Robertson, 1977), and to techniques such as theme generation and summarizing (Salton, Allen, Buckley & Singhal, 1994). Since it was recognized that not only matching terms in queries and documents, but also the user and the task he/she performs are involved in an information retrieval system, information retrieval has become an interdisciplinary area of research that increasingly draws on information seeking research (for example, Vakkari, 1999).

To support the choices retrievers make, the role of context, and in particular the user’s tasks, has received considerable attention recently. Despite this, context and tasks are ill-defined concepts, investigated at different levels of abstraction (see Cool & Spink (2002) for an overview). At the highest level context is seen as a user’s environment, for example an organizational or work task setting, the lowest level is a linguistic level, for example investigating

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query disambiguation in cases where documents have the right terms but the wrong context (for example, Lawrence, 2000). Many studies concentrate on generic aspects of (information seeking) tasks, in pursuit of grasping the changing level of users' understanding during the course of a search (for example, Belkin, 1993). Byström and Hansen (2002) provide a conceptual framework in which a (real-life) work task drives one or more information seeking tasks (the need for information), which may comprise one or more information retrieval tasks (consulting a source). From this point of view, a retrieval task is inextricably bound to a work task, which is the purpose to re-use material. The use of ontologies may enhance the retrieval process in several respects. A knowledge-rich indexing vocabulary, by providing a structured, conceptual hierarchy of concepts, may help retrievers of material to accurately formulate their need for information. Because users can specify precisely what they look for, the use of ontologies has a high potential to yield precise search results. Ontologies not only allow for a precise representation of a domain; tasks can also be represented in an ontology. This means that material can be annotated not only with domain information (including semantic descriptions of the material), but also with task information. The difficult task of instructional design, but also domain specific tasks, such as maintenance of complex systems, can be represented in ontologies. Because it is the work task that eventually leads to consulting a source, it is anticipated that retrieval performance can be enhanced through providing extensive, structured task-based retrieval support.

2.8 The re-use process

Re-use does not happen only by retrieving material. From the retrieved material, instructional material must be created, such that teachers and learners can use it. Creating instructional material that stimulates teachers and learners to use it is generally not regarded as an easy job. The creation of instructional material can be based on a design. A design is essentially a specification of a learning goal linked to an instructional strategy, possibly refined into teacher and learner activities. A design can function as a skeleton that is filled with fragments and instructional editing. Instructional material can also be created without a design. In any way, creating material leads to a retrieval task necessary to collect fragments that will be used in instructional material. The product of design and development, instructional material, is used in a lesson or to learn from. Creating and using material each drive different needs for information. To some degree different metadata is required to support creation and usage of material. In this thesis the emphasis is on the metadata that is relevant for people wanting to retrieve fragments to create instructional material, which should lead to application of the developed product in a teaching or learning situation. Several theories have been proposed to provide foundations for creating lesson material. Instructional design theory is defined by Merrill (1997) as a set of prescriptions for determining appropriate instructional strategies, to enable learners achieve instructional goals. With the increased use of computers for learning, training and instruction theories for instructional design have evolved. The foundations on which instructional design theories are based have evolved over the past half-century from behaviorism to cognitive science and
constructivism. (See Tennyson and Scott, 1997 for an overview). The initial narrow focus on programmed instruction gradually gave way to a multidimensional field of study integrating psychology, technology, evaluation, measurement and management. To meet the expectations of re-use realized though an object-oriented approach, only more recently learning object design theories and approaches have been developed.

Gagné (1985) assumed that there are different kinds of instructional goals and that different instructional strategies are required in order for the learner to most efficiently and effectively reach a given kind of instructional goal. Instructional design theories based on this assumption consist of three components: the knowledge or skill to be learned, the strategies used to promote this learning, and relations between the knowledge and strategies, in the form of: “if [knowledge outcome] then [specific instructional strategy]”. Gagné proposed five categories of knowledge outcome: intellectual skills, cognitive strategies, verbal information, motor skills, and attitudes. Gagné also proposed nine events of instruction: gaining attention, informing the learner of the objective and activating motivation, stimulating recall of prior knowledge, presenting the stimulus material, providing learner guidance, eliciting performance, providing feedback, assessing performance, and enhancing retention and transfer. For each pair of knowledge outcome and instructional event he then identifies the conditions necessary for learning to be efficient and effective.

With Component Display Theory (CDT) (Merrill, 1983), Merrill attempted to build a principled mechanism that effectively allowed learners to control their path through instructional material. The knowledge or skill to be learned consists of a two way classification based on two dimensions: “performance” and “content”. The performance dimension is: remember instance, remember generality, use generality with an unencountered instance, and find a new generality. The content dimension is defined as facts, concepts, procedures and principles. At the core of the strategies required to promote learning are Primary Presentation Forms: expository generality (rule), expository instance (example), inquisitory generality (recall), and inquisitory instance (practice). Secondary Presentation Forms consist of information added to facilitate learning such as attention focusing help, mnemonics, and feedback. In addition, Interdisplay Relationships are sequences involving example - non-example matching, example divergence and range of example difficulty. For each performance-content classification, CDT prescribes the combination of Presentation Forms and Interdisplay Relationships.

Merrill realized that learners needed control over the individual strategies instead of being presented with larger sequences of material, and that an object-oriented approach would be the way to achieve this. CDT is an intellectual parent of many other important instructional theories and approaches, including Merrill's later Instructional Transaction Theory (ITT) (Merrill, 1997), Wiley's Learning Object Design and Sequencing Theory (LODAS) (Wiley, 2000), and Cisco Systems' Reusable Learning Objects Strategy (Cisco Systems, 2001). (These theories and approaches were introduced in Section 2.2).

Merrill's Instructional Transaction Theory (ITT) (Merrill, 1997) is an attempt to define the complete set of prescriptions to drive automated instructional design and development. In ITT, Merrill further specifies the format in which the material is to be expressed (knowledge objects) and the ways in which pre-specified strategies (instructional transaction shells) should operate on knowledge objects. Knowledge objects (entities, activities, processes and
properties) are containers consisting of compartments (slots) for different related elements of knowledge (the knowledge components). The framework of a knowledge object is the same for a wide variety of different topics within a subject domain. The contents of a given compartment differ, but the nature of the knowledge element in a given compartment is the same. All knowledge objects have a set of information slots including: name, portrayal, and description. The name contains one or more symbols or terms that reference the knowledge. The portrayal is one or more multimedia objects (text, audio, video, graphic, animation) that will show or represent the knowledge object to the student. The description slot is an open compartment into which an author can place any desired information about the knowledge object. It is possible for the description slot to be subdivided into several subslots. These might include function, purpose, etc., and may be defined by a given user. Transaction shells consist of rules for selecting and sequencing knowledge objects, for example, identification, execution, explanation, judging, classification, generalization and transfer. The knowledge representation used for ITT shows how knowledge can be structured in automated instructional design. However, for a human person to find the knowledge objects from some repository and construct instructional material, the attributes of knowledge objects (name, portrayal, description) may be insufficient.

While the goal of automated instructional systems is worthwhile, there are two important reasons to support manual retrieval of material and manual development of instructional material. First, human assembly of material works best with small objects (fragments). The majority of the data available on the public Internet are "small objects" (images, text files, etc.). Second, before humans can build automated systems to assemble material, they must first learn the lessons to be gained by combining those by hand (Wiley, Recker & Gibbons, 2000).

In LODAS, Wiley (2000) provides a theoretical basis for (by hand) design and sequencing of learning objects. LODAS presents guidelines for the analysis and synthesis of an undifferentiated content area (for example, English), the application of which produces specifications for the scope and sequence of learning objects. The theory also provides a taxonomy of five learning object types and provides design guidance for the different types of learning objects. Wiley gives a worked example of this process, and connects the instructional design theory to the taxonomy by providing guidance of the type "for this type of learning goal, use this type of learning object."

There is a lack of practical experience with learning object design theory such as Wiley's and with the use of annotation structures for instructional design (for example IMS Learning Design Information Model (2003)). It seems that to gain experience the direction will be a pragmatic approach by supporting retrieval of material in such a way that it is clear what designers, developers, teachers and learners can do with the material.

A task-ontology, which is a conceptual decomposition of a real-life work task, may be an adequate means to take a practical approach. To develop instructional material two tasks are relevant: the task of specifying a design, and the task to be learned. A task-ontology for instructional design can be used to formulate a learning goal, strategy, and to further specify a strategy into tasks teachers and learners should carry out with the material. A task-ontology that reflects the task (or knowledge or skill) to be learned, for instance an operational task such as maintenance, can guide the development of instructional material. Examples of
these task types will be discussed in more detail in Chapter 3. Task-ontologies can provide the extensive re-use support that may bring the promise of creating a better product in less time closer to reality.

2.9 Conclusions

A review of the literature has learned that there are several approaches to solve problems with the material handling processes: analysis, storage, retrieval and re-use. The processes form a value-adding chain from analysis of source material to re-use of instructional material. In each process value is added to material in order to enable re-use. There is theoretical and practical support for analysis and segmentation of source material. Problems with decentralized storage are approached by mapping customized annotation structures. In an increasing degree there is support for how to create and use instructional material. Last but not least, there are several standardized annotation structures and indexing vocabularies that support retrieval of instructional material of different grain sizes, allowing a wide public to exchange instructional material. These are considerable achievements, given that learning object technology is relatively new. In spite of this, not all problems occurring in the material handling processes are solved. There is still room for improvement. A knowledge-rich indexing of material using ontologies may provide added value to the material handling processes. Whether ontologies can provide the expected added value is empirically investigated in the next chapters.