MAPPING LOCAL ONTOLOGIES: AUTHENTIC SEMANTICS FOR LEARNING OBJECT EVALUATION

by

Jerry Zhigang Li

M.Ed., University of Sheffield, 1995
MBA., University of Salford, 1996

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APPROVAL

Name: **Jerry Zhigang Li**

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Title of Thesis: **Mapping Local Ontologies: Authentic Semantics for Learning Object Evaluation**

Examining Committee:

Chair:

____

Dr. Chris Shaw
Associate Professor
School of Interactive Arts and Technology

____

Dr. John Nesbit
Senior Supervisor
Associate Professor
Faculty of Education

____

Dr. Marek Hatala
Supervisor
Associate Professor
School of Interactive Arts and Technology

____

Dr. Dragan Gasevic
External Examiner
Post-doctoral Fellow
School of Interactive Arts and Technology

Date Defended/Approved: July 20, 2006

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ABSTRACT

Currently, there are no feasible subject taxonomies for learning objects. Large and standardized library classification systems do not present subject descriptors matching varying local practices. When searching for learning objects, teachers, instructional designers and students prefer to use subject terms with which they are already familiar. This research describes the form and function of a mapping ontology created to translate between a central subject ontology and a local subject ontology. An implemented case shows how the mapping ontology can allow teachers working with the British Columbia Ministry of Education science curriculum to search and evaluate learning objects catalogued in a repository (eLera) according to a modified form of Dewey Decimal Classification. An information retrieval evaluation showed that subject search with ontology mapping has greater retrieval precision level than simple keyword search. A usability survey showed a strong user preference for subject search with ontology mapping over keyword search.

Keywords: e-learning, Web-based instruction design, learning object review, ontology mapping, information retrieval.

DEDICATION

To my family and my beloved wife for their unconditional love and support

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LIST OF ABBREVIATIONS AND ACRONYMS

ARIADNE	Alliance of Remote Instructional Authoring and Distribution Networks for Europe
BC. IRPs	British Columbia Integrated Resource Packages
CANARIE	Canada's Advanced Internet Development Organization
CanCore	Canadian Core Learning Resource Metadata Specification
CELTS	Chinese E-Learning Technology Standard
CLOE	Co-operative Learning Object Exchange
CMC	Computer Mediated Communications
DCMI	Dublin Core Metadata Initiative
DDC	Dewey Decimal Classification
DLNET	Digital Library Network for Engineering and Technology
ECL	EduSource Communication Layer
eLera	E-Learning Research and Assessment Network
eLera-DDC	Modified Dewey Decimal Classification System used in eLera
IEEE	Institute of Electrical and Electronics Engineers, Inc.
IMS	IMS Global Learning Consortium, Inc.
IR	Information Retrieval
ISO	International Organization for Standardization
LOM	IEEE Learning Object Metadata
LORI	Learning Object Review Instrument
McREL	Mid-continent Research for Education and Learning
MERLOT	Multimedia Educational Resource for Learning and Online Teaching
NCSA	National Center for Supercomputing Applications
NSDL	National Science Digital Library
OCLC	Online Computer Library Centre
OWL	Web Ontology Language
OWLJessKB	A Description Logic Reasoner for the W3C's Ontology Web Language
RDF	Resource Description Framework
SCORM	Sharable Content Object Reference Model
SGML	Standard Generalized Mark-up Language
SKOS	Simple Knowledge Organization System
W3C	World Wide Web Consortium

CHAPTER 1.
OVERVIEW AND GOALS OF THESIS

The word *technology,* which originated from the Greek tekhnologiã, is defined in the American Heritage Dictionary (2000) as "systematic treatment of an art or craft." As for the definition of education technology or instructional technology, there is no single widely accepted definition. Some educators see technologies as being tools for instructional design. They describe educational technologies as "tools used in formal educational practice to disseminate, illustrate, communicate, or immerse learners and teachers in activities purposively designed to induce learning" (Garrison & Anderson, 2003, p.34). However, other schools of thought focus on techniques rather than tools. The Education Resources Information Center (ERIC), for example, introduces educational technology as:

> Systematic identification, development, organization, or utilization of educational resources and/or the management of these processes - occasionally used in a more limited sense to describe the use of equipment- oriented techniques or audiovisual aids in educational settings (ERIC, 1969).

The present research, however, falls most clearly within the definition of educational technology given by the Association for Educational Communications and Technology (AECT, 2001): "the theory and practice of design, development, utilization, management, and evaluation of processes and resources for learning." The topic of this thesis relates to the theory and practice of managing of resources for learning.

Technology in education has a long history, which extends back to the clay tablets, slate drawing boards, and handmade paper of pre-Gutenberg education (Garrison & Anderson, 2003). The technologies most associated with education include printed textbooks, mass broadcast media, digital multimedia, and computer-mediated conferencing. In recent decades, the advances of personal computers with the support of the Internet have made profound changes in our society. Electronic communications and digital networks are transforming the way we work and are reshaping personal communication and entertainment. The Internet is constantly evolving and changing as applications are developed that exploit its capacity for information communication and processing. It has been seen as a new way to deliver instruction, a rich source of resources for students to explore, a new medium for knowledge construction offering opportunities for students to discuss, share, and collaborate on their knowledge products (Resnick, 1996). Garrison and Anderson (2003, p. 1) commented that "we are only experiencing e-learning in its early forms and have much to learn of its inherent capabilities and the creation of a new learning ecology." In the foreseeable future, teacher and student will be able to use agents that incorporate various types of intelligence that will allow fruitful searching, navigation, and exploitation of the *semantic web,* which adds artificial intelligence to the Web and can be navigated and processed by both humans and nonhuman autonomous agents (Berners-Lee & Hendler, 2001).

Information technology advancement has shifted knowledge representation from paper to digital forms. There is a rapid increase in the creation and collection of digital resources as a wide variety of communities have begun to digitize and store information in databases. Web based digital resources will play an increasingly important role in our everyday life. Education institutions have invested significant resources in creating web-based content for delivery through proprietary learning management systems.

With this rapid development in e-learning, some problems have emerged. E-learning designers realised that it is costly to create and maintain e-learning content and often found the content they want to develop has already been created by a number of other institutions. But designers still have to "re-invent the wheel" because the content format does not fit their needs and it can not be run on their system. Even users within the same institution may be unable reuse each other's content because it is not properly catalogued and is not searchable. Furthermore, modification of a small portion of existing content may need a change in the whole course. Often, local software developers and system administrators have to be involved in addressing such issues. Course instructors often complain that course content is not flexible enough for them to move and re-order course content. According to Hodgins (2000), to overcome such obstacles, designers have found they must answer the following questions.

- How will we mix and match content from multiple sources?
- How do we develop interchangeable content that can be reused, assembled, and disassembled quickly and easily?
- How do we ensure that we are not trapped by a vendor's proprietary learning technology?
- How do we ensure that our learning technology investments are wise and risk-averse?

A very important step toward the solution to those questions is to share a *standard* so that everyone can talk to each other via a common interface. In the past, standards have brought many revolutionary changes in our lives. For example, the standardization of voltage and plugs in the electrical world has made our everyday life much easier. In the world of telecommunication, TCP/IP and HTTP as Internet standards have enabled the world to communicate online.

Therefore, standards for e-learning are equally important for success of the knowledge economy. In the e-learning world, standards are generally developed for the purposes of ensuring interoperability, accessibility and reusability of Web-based learning content.

> ***Interoperability***: the ability to take instructional components developed in one location with one set of tools or platform and use them in another location with a different set of tools or platform.
>
> ***Accessibility***: the ability to locate and access instructional components from one remote location and deliver them to many other locations.
>
> ***Reusability***: the flexibility to incorporate instructional components in multiple applications and contexts.
>
> (Advanced Distributed Learning, 2004)

According to Friesen (2004), standards typically consist of:

- a data model which specifies the standard's *normative* content in abstraction;
- one or more *bindings*, which specify how the data model is expressed in a formal idiom, which is most often XML, and perhaps more rare;
- an *API* (Application Programming Interface) or *service definition* that defines points of contact between cooperating systems.

Since 1986, Standard Generalized Mark-up Language (SGML) as a mature standard has numerous implementations and a rich variety of available tools (W3C, 1995). Several of its subsets such as HTML (W3C, 1999a), XML (W3C, 1996) are widely used. XML, in particular, offers a platform-independent means of describing the logical structure of a document, and its presentation can be customized. More and more commercial vendors are designing products that make good use of XML. The major

Internet web browser companies such as Netscape and Microsoft have built-in XML support tools in their browsers. The emerging e-learning standards are also making extensive use of XML in their designs. This includes Dublin Core, IMS Learning Resource Meta-Data Information Model (IMS, 2001), and the Canadian Core Learning Resource Metadata Specification (CanCore: Friesen, Fisher, Tozer, Roberts, Hesemeier, & Habkirk, 2004) and Sharable Content Object Reference Model (SCORM: Advanced Distributed Learning, 2004).

Thanks to the e-learning standards, the emergence of learning objects and repositories have offered rich new ecologies of learning. Learning objects can be seen as any digital resource that can be reused alone or in combination to support learning. The main feature distinguishing learning objects from other educational applications is their ready availability through web-based repositories or collections that can be searched with standardized metadata. Within the next five years, the U.S. National Science Digital Library (NSDL) is predicted to grow to include as many as 100,000 collections representing over a million learning objects (Saylor, 2002).

A classification system is "an arbitrary yet purposeful division of concepts or things into groups" (Li, Gašević, Nesbit, & Richards, 2005). The widely adopted IEEE Learning Object Metadata (LOM) standard that specifies descriptive attributes of learning objects has a classification category that allows repositories to adopt and specify any subject classification system. As a result, one repository conforming to the IEEE LOM might adopt the Library of Congress (LOC) system (Library of Congress, 2005) while another might adopt the Dewey Decimal Classification (DDC) system (Online Computer Library Center, 2005). This situation shows the need to balance the benefits of a standard subject classification system against the benefits of a subject classification system that is fitted to the properties of the repository content and the specific needs of the repository users.

With this background, my research addresses the emerging issues on sharing learning resources with local needs and my goal is to provide a feasible solution to improve the interoperability, accessibility and reusability of learning resources.

Research Question

As mentioned earlier, the main feature of learning objects is their ready availability through web-based repositories or collections that can be searched with standardized metadata. Classification is one of the standard metadata descriptors for learning objects. Currently, however, there is no widely accepted subject taxonomy for learning objects. Large and standardized library classification systems do not present subject descriptors that match varying local practices. When searching for learning objects, teachers, instructional designers and students prefer to use subject terms with which they are already familiar (Recker, Dorward, & Nelson, 2004).

In fact, the current compromise provides a poor service. It has led to a multitude of subject classification systems, usually developed as variants of existing library classification systems. Even within the same domain, there are multiple ways of classifying resources. For example, iLumina (iLumina, 2004), a digital library of sharable undergraduate teaching materials for chemistry, biology, physics, mathematics, and computer science, uses a modified version of the Library of Congress classification system. CanCore (Friesen et al., 2004) recommends Dewey Decimal Classification (DDC) as the basic subject taxonomy. Other repositories, such as MERLOT (2005), or the National Science Digital Library (NSDL) Middle School Portal (National Science Digital Library, 2006), use their own classification system to classify learning resources. All these taxonomies have been developed and maintained independently of each other. This blooming variety of domain taxonomies threatens to hamper the interoperability of learning object repositories and confuse users working across multiple repositories.

However, requiring all repositories and users to adopt a single standard classification system is not the solution. School teachers, university instructors, instructional designers and students prefer to use familiar terms for subject matter, learning objectives, and achievement level, which have been established in a local community of practice. As teachers compare and select objects to advance the intellectual and social development of students, they must examine the pedagogical assumptions of objects; judge whether students are ready to learn from them, and determine whether they match learning goals. However, these tasks are made much more difficult if the information provided about the objects is expressed using terms with which they are not familiar.

The aforementioned issues lead to a fundamental question which drives the research reported here. That is, how can one keep using a familiar, local classification system, but still be able to search centralized digital libraries based on a different classification system?

Structure of the Thesis

In this thesis, the strategy adopted to pursue to the above question is to adopt a core classification system as a universal subject taxonomy into which a large number of local subject taxonomies can be mapped. This strategy is implemented and evaluated in the context of eLera, a website supporting the evaluation of learning resources.

Chapter 2 describes the goals and operation of eLera; Chapter 3 discusses interoperability problems with domain ontologies and the design and implementation of ontology mapping in eLera; Chapter 4 reports on an information retrieval evaluation of the ontology mapping implemented in eLera; Chapter 5 reports on a usability evaluation of the ontology mapping implementation in eLera; Chapter 6 is the discussion and conclusion.

CHAPTER 2.
QUALITY EVALUATION OF LEARNING RESOURCES

The focus of this chapter is on the issues of learning object quality evaluation, and on models and tools for evaluation which I have helped to develop. eLera, the learning resource evaluation website described here, was used as a test bed for the ontology mapping technology which is the primary contribution of this thesis.

Learning objects are digital learning resources that are often available through web-based repositories searchable with standardized metadata. There are many benefits to using learning objects: They can be designed to support learning through multimedia, an approach whose effectiveness has been repeatedly demonstrated (Mayer, 2001); they can be designed to adapt to the learner's level of knowledge; and they can offer self-diagnostic assessment.

However, the production of learning objects occurs in a variety of settings, many of which lack quality control procedures or guidelines. A brief survey of objects in any of the larger databases offers abundant evidence that authors frequently fail to apply design principles that have been established in the fields of instructional design, instructional psychology and the learning sciences. Further, many objects registered in repositories appear to have never been learner-tested or subjected to other processes of formative assessment. In my view, there is a quality problem that demands a multifaceted solution involving better education of learning object designers, design and development models that incorporate formative quality assessment and learner-testing, and summative review provided in association with the repository in which the object is registered. The aggregated ratings and comments produced by summative reviews should be maintained as a form of metadata that users can apply to search, sort, and select objects.

The variety of settings in which learning resources are produced and consumed suggests that no single evaluation model is sufficient for all settings. For example, chemistry teachers within a school district who have agreed to develop shared resources have assessment requirements that differ from corporate trainers who develop resources to support an industry-wide certification program. The model presented in this chapter is intended to cover a wide range of professional settings, but it may not fit every case in which learning object evaluation is needed.

Evaluation Methods and Models

Although most repositories do not offer evaluation tools, a few different approaches to learning object evaluation have been established. Evaluation models are typically a combination of technical tools, evaluation rubrics, and community practices. In this section, three models for learning object evaluation are discussed.

CLOE

The Co-operative Learning Object Exchange (CLOE), jointly developed by seventeen Ontario universities to facilitate the design and application of multimedia-rich learning resources, operates a structured review process (Clarke, 2003). A learning object submitted to CLOE is first examined by the editor-in-chief to decide if it meets specified technical requirements. The object is then either returned to the author for revision, or forwarded to an instructional design reviewer and content reviewers. The instructional design reviewer gives a binary decision (*go* or *no-go*). Normally, content is reviewed by two content reviewers. When they disagree, the decision to approve the object falls to a third content reviewer. CLOE provides three broad evaluative dimensions: quality of content, effectiveness as a teaching/learning tool, and ease of use.

MERLOT

MERLOT (www.merlot.org) is a repository containing educational resources classified into seven broad subject categories: Arts; Business; Education; Humanities; Mathematics and Statistics; Science and Technology; Social Sciences. Each category is divided into sub-categories, resulting in more than 500 subjects. MERLOT provides tools for both individual member comments and peer review. In both types of evaluation, resources are rated on a five-point scale. An object may be selected for peer review by an editorial board representing one of 14 discipline-based communities within the collection. The commonly practiced peer review process in MERLOT is similar to that for CLOE, except that there is no provision for an instructional design reviewer.

DLNET

The U.S. National Sciences Digital Library is a federated repository that includes DLNET, the Digital Library Network for Engineering and Technology (www.dlnet.vt.edu). DLNET uses a subject taxonomy that was adapted from the INSPEC taxonomy of scientific and technical literature (www.iee.org/Publish/Inspec).

Like MERLOT, DLNET maintains a two-tier evaluation system allowing review by expert peers and “public review” by users at large. But it differs from MERLOT in that an object is not published in the repository until it has been approved by peer review.

The function of public reviews is to provide an ongoing ranking of published objects by users.

DLNET reviewers fill out an instrument containing a single comment field and 11 items rated on a 5-point scale. DLNET currently allows members to publish multiple reviews on the same learning object and currently provides no statistical aggregation of rating data.

Models and Tools

These three examples (CLOE, MERLOT, and DLNET) demonstrate a common model with variations. Each is formed from (a) a searchable database of learning resource metadata that more or less conform to the IEEE learning object metadata standard; (b) a subject taxonomy constituting one component of the metadata; (c) evaluation criteria in the form of guidelines or a structured instrument; (d) a process for conducting and publishing reviews including restrictions on who can review; (e) a structured form in which all reviews are published. Such systems are socio-technical phenomena that can be analyzed and empirically researched.

The two tiers of individual user and peer review that we see in MERLOT and DLNET mirror the two different types of consumer product evaluation systems that have proliferated on the Web. For example, at one video game review site (www.videogamereview.com), any user can register to rate and comment on three quality dimensions (game play, graphics, sound) of a video game. Similarly, at a general consumer product review site (www.reviewcentre.com), any user can rate products on the two dimensions of quality and value for money, as well as record comments. In contrast to these open evaluation systems, other product evaluation sites present only expert reviews. For example, at a DVD review site (www.dvdfile.com) experts evaluate DVD movies on the quality of video, audio, supplements, interactive features, and value for money.

As with most of the product review sites, the evaluation processes of learning object repositories provide few opportunities for interaction among expert reviewers (e.g. content experts and instructional designers), and even fewer for interactions between expert and consumer reviewers (e.g., learners and teachers). Such interactions are potentially important because, in research settings, reviewers have been consistently observed to modify their evaluation of a learning object after being presented with reviews that differ from their own (Vargo, Nesbit, Belfer, & Archambault, 2003). This lends weight to the view that experts and consumers can affect each others' opinions and form convergent evaluations demonstrating greater validity than either could achieve independently.

Interactions among reviewers also present a powerful opportunity for professional development of teachers, instructional designers and media developers. We believe that an evaluation model that educates a significant proportion of the designer population about learning object quality will raise the overall quality of the resource pool, and is a much needed complement to models aiming for a high review throughput.

The major learning object repositories have not exploited the meta-evaluation and recommendation features that are now available on popular websites such as Amazon (www.amazon.com). We see a need to extend the current evaluation models and tools to incorporate these features.

E-Learning Research and Assessment Network (eLera)

eLera is a website designed to support a distributed community of teachers, instructors, students, researchers, instructional designers, and media developers. Under development since September 2002, the initial version of eLera was publicly released in November 2003 at www.eLera.net. eLera is a member of eduSource Canada, a network of interoperable Canadian repositories federally funded by CANARIE Inc. I have been involved in design and development of eLera since 2002. The eLera research on collaborative evaluation of learning objects is relevant to my thesis research because it forms the foundation on which my thesis research is based.

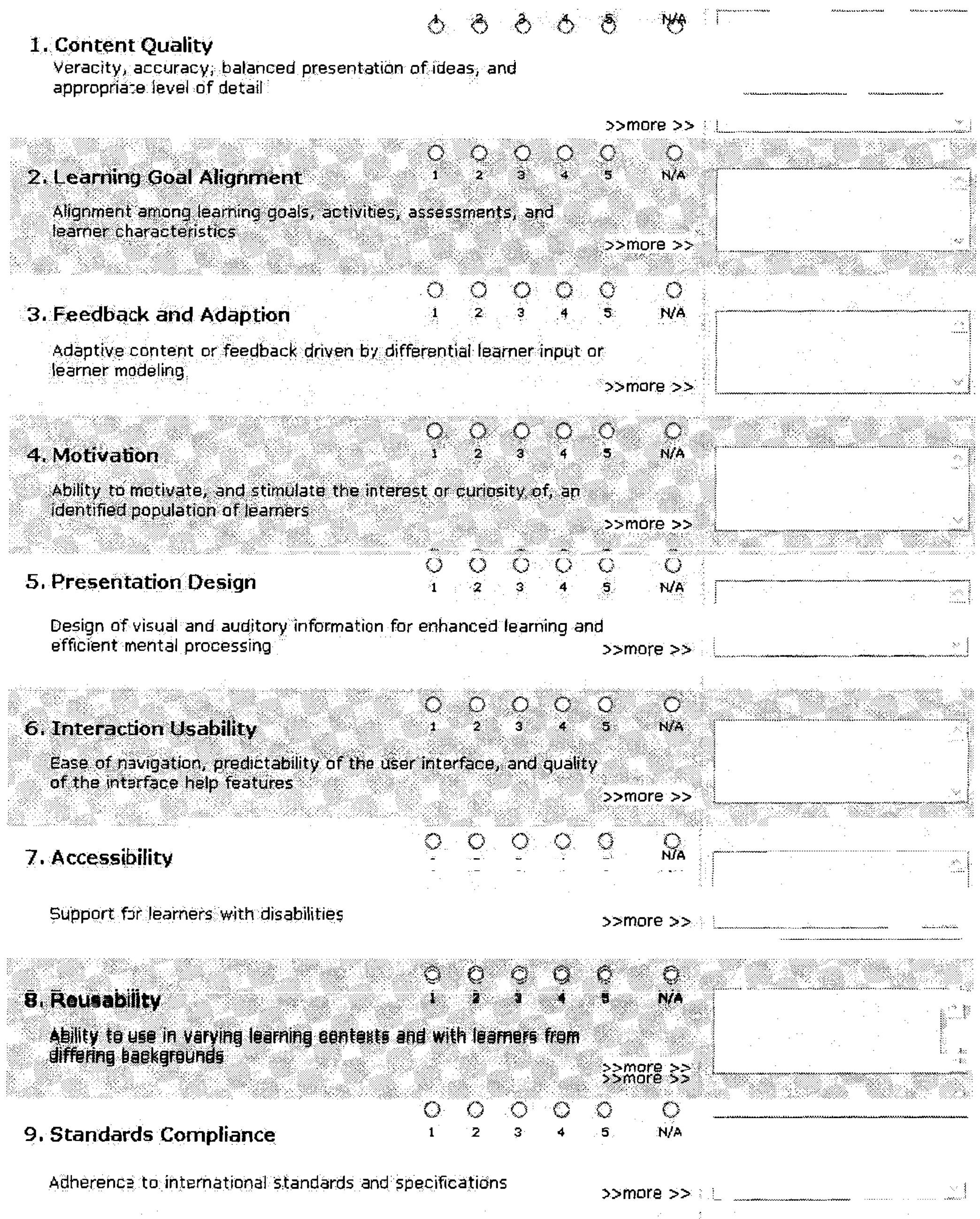
Basic features

Like MERLOT and DLNET, eLera maintains a searchable database of learning object metadata and reviews, and provides tools and information for learning object evaluation. eLera complies with the IEEE learning object metadata standards as interpreted by the CanCore guide (Friesen, Fisher, Tozer, Roberts, Hesemeier, & Habkirk, 2003). With permission of the Online Computer Library Centre, it uses a modified version of the Dewey Decimal Classification System as subject taxonomy. eLera includes evaluation forms and reports, statistical aggregation of ratings, and a "my collection" feature allowing members to assemble frequently used objects. eLera is available in French and Chinese versions. It can be used to conduct a federated search of other repositories using the eduSource Communication Language (Hatala, Richards, Eap, & Williams, 2003).

Research oriented

While similar in form to other learning object repositories, eLera has unique goals that will shape its future development. eLera is intended to facilitate research on learning object evaluation and design. Evaluation data collected through eLera will be used to test the validity and reliability of instruments and evaluation models. eLera moderators can access detailed data pages for each object that present all ratings and comments in tabular form. These data have been used to study the application of Bayesian networks to learning object evaluation (Kumar, Nesbit, Winne, Hadwin., & Han, in press).

eLera will be used for research on collaborative evaluation and the interrelation between design and formative evaluation in e-learning development communities. To measure the effects of collaboration, eLera allows us to easily capture the distribution of quality ratings before and after discussion sessions. We expect to create versions of eLera to support successful workflow within teams that develop learning objects. For example we may create an evaluation instrument in which items become activated or deactivated as the object passes through defined stages. This enterprise leads immediately to an examination of critical factors influencing learning object quality in design and development: What work is completed in each stage of the development process? Who should monitor quality at each stage? What information must be communicated to assure quality?



1. Content Quality — 1 2 3 4 5 N/A
Veracity, accuracy, balanced presentation of ideas, and appropriate level of detail
>>more >>

2. Learning Goal Alignment — 1 2 3 4 5 N/A
Alignment among learning goals, activities, assessments, and learner characteristics
>>more >>

3. Feedback and Adaption — 1 2 3 4 5 N/A
Adaptive content or feedback driven by differential learner input or learner modeling
>>more >>

4. Motivation — 1 2 3 4 5 N/A
Ability to motivate, and stimulate the interest or curiosity of, an identified population of learners
>>more >>

5. Presentation Design — 1 2 3 4 5 N/A
Design of visual and auditory information for enhanced learning and efficient mental processing
>>more >>

6. Interaction Usability — 1 2 3 4 5 N/A
Ease of navigation, predictability of the user interface, and quality of the interface help features
>>more >>

7. Accessibility — N/A
Support for learners with disabilities
>>more >>

8. Reusability — 1 2 3 4 5 N/A
Ability to use in varying learning contexts and with learners from differing backgrounds
>>more >>

9. Standards Compliance — 1 2 3 4 5 N/A
Adherence to international standards and specifications
>>more >>

Figure 1: LORI as seen by a reviewer

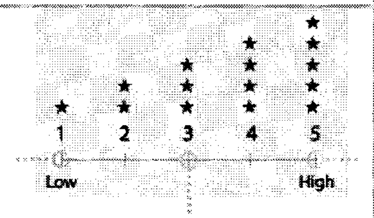
Low One of the following characteristics renders the learning object unusable. • No learning goals are apparent. • The assessments, learning activities and other content are substantially mismatched. • The learning goals are not appropriate for the intended learners.	**Learning Goal Alignment** 	**High** Learning goals are declared, either within content accessed by the learner or in available metadata. The learning goals are appropriate for the intended learners. The learning activities, content and assessments provided by the object align with the declared goals. The learning object is sufficient in and of itself to enable learners to achieve the learning goals.
Example In a learning object on heart function, seven out of ten questions on a post-test correspond to an animation showing the pumping action of the heart. The intended group of learners would be highly unlikely to infer the answer for three of the questions from information presented in the animation, even though the instructions imply that no additional resources are necessary.		

Figure 2: The detailed rubrics for learning goal alignment

Learning object review instrument

The eLera website allows users to evaluate resources with the Learning Object Review Instrument (LORI: Nesbit, Belfer, & Leacock, 2003). Figure 1 shows how LORI appears to online reviewers. Figure 2 shows an example of the additional information about an item that reviewers can access within the review form by clicking *more*. For each item, reviewers can enter comments and ratings on a 5-point scale. Reviewers can skip items that they are unable to assess. Each review is published as a web page in eLera. Ratings are averaged over items and reviewers to obtain a mean rating that is used to sort search results.

LORI has been iteratively developed through reliability and validity studies with instructional developers and teachers (Vargo, Nesbit, Belfer, & Archambault, 2003). Version 1.5 of LORI is comprised of the following nine items selected to concisely specify a broad range of quality factors.

Content quality

The single most salient aspect of quality in many discussions of educational materials is quality of content. Sanger and Greenbowe (1999) and Dall'Alba et al. (1993) demonstrated that biases and errors can easily slip into educational materials and cause problems for students. The content quality item in LORI asks reviewers to consider the veracity and accuracy of learning objects, in addition to assessing whether the object provides a balanced presentation of ideas and contains an appropriate level of detail.

Learning goal alignment

Aligning instruction and assessment can improve learning outcomes (Cohen, 1987). This LORI item asks reviewers to consider the degree to which the assessments and activities presented in the material accurately represent intended learning goals.

Feedback and adaptation

Learners tend to be poor monitors of their own learning (Zimmerman, 1998) and of their need for help (Aleven, Stahl, Schworm, Fischer, & Wallace, 2003). Learning objects often provide feedback to help learners gauge their progress. The best learning objects do this adaptively. That is, they customize the learning environment, including the feedback and the content itself, to the needs to each learner (Hadwin & Winne, 2001). This LORI item asks reviewers to evaluate learning objects on the effectiveness with which they adapt to learners' behaviours.

Motivation

According to Eccles and Wigfield (2002), individuals are motivated to engage in a task if that task has value to them and if the cost of performing the task does not outweigh its expected value. Learning objects that are relevant to the learner's personal goals and offer achievable challenges will motivate learners and lead to increased interest in the topic.

Presentation design

The visual appearance and sounds presented by a learning object, particularly as they relate to information design, affect the object's aesthetic and pedagogical characteristics. Decisions about presentation design should be informed by instructional and cognitive psychology, especially the theories and principles of cognitive load (Merrienboer & Sweller, 2005), multimedia learning (Mayer, 2001), and information visualization (Parrish, 2004; Tufte, 1997).

Interaction usability

Learning objects that receive a high score on interaction usability are easy to navigate. They allow the learner to see what options are available, predict the outcomes of actions, and return to where they were if they make a mistake (Norman, 1988). Clarity, redundancy, and system responsiveness contribute to achieving these goals (Selvidge, Chaparro, & Bender, 2001; Wickens, Lee, Liu, & Gordon Becker, 2004).

Accessibility

Accessibility is a significant issue in the digital learning environment (Section508, 1998). For students to use a learning object, they must be able to access its content. Although software developers have come a long way in making computerized materials technically available to users across a range of platforms, there is still a significant access issue for learners with disabilities. For example, many learning objects provide visual information with no explanatory audio or text, thus rendering their content inaccessible to sight-impaired learners (Paciello, 2000). Because this LORI item is tied to detailed W3C (W3C, 1999b) and IMS (2003) guidelines, we recommend that most reviewers use a validation service such as WebXACT (n.d) or A-Prompt (n.d.) to assist in determining an object's accessibility rating.

Reusability

Although reusability is frequently touted as one of the key benefits of learning objects, the reality often does not live up to the promise (Wiley, 2002). This LORI item asks reviewers to consider whether an object is likely to be effective across a broad range of contexts, recognizing that no single object will be appropriate for all contexts in which particular content is taught.

Standards compliance

As with accessibility, evaluating standards compliance requires technical knowledge beyond the preparation of most educators. Nevertheless, adherence to international technical specifications and standards is an important aspect of quality that may affect such matters as whether the learning resource can display correctly in the user's browser. Notably, this LORI item also reminds designers that providing standard metadata allows users to more easily register the object in a repository.

Figure 3: An eLera request as viewed by the moderator who created it

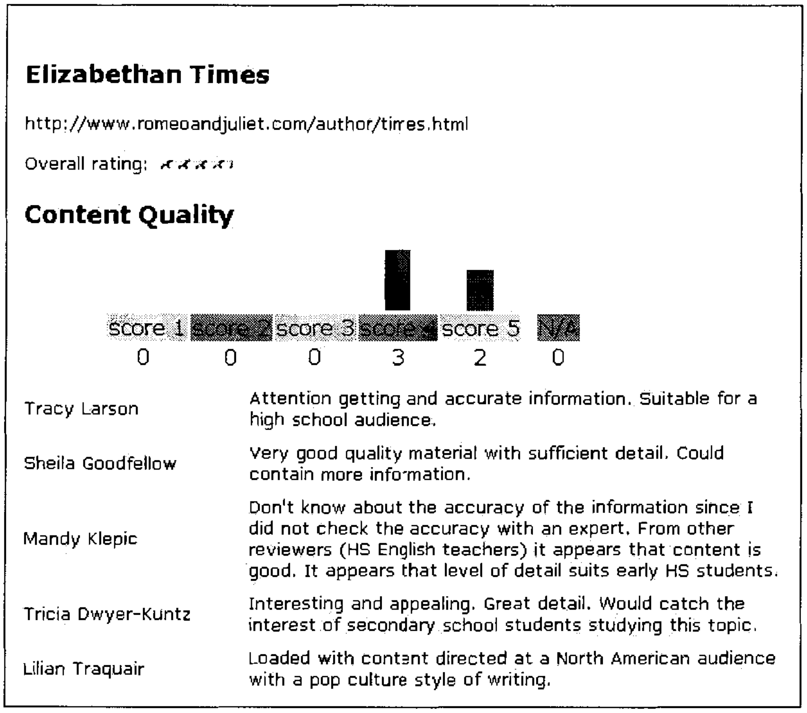


Figure 4: The distribution of ratings on a LORI item (content quality) as seen by collaborating reviewers

Tools for collaborative evaluation

eLera's tools for collaborative evaluation are designed to support the convergent participation model defined and tested in previous research (Nesbit, Belfer, & Vargo, 2002; Nesbit, Belfer, 2004; Vargo, Nesbit, Belfer, & Archambault, 2003). In this model, small evaluation teams are formed from participants representing relevant knowledge sets and interests (e.g., subject matter expert, learner, instructional designer). A team leader or moderator chooses objects for review, schedules the review activity, and invites team members. Currently, moderators can use eLera's request feature (Figure 3) to invite members to review an object. Members may choose to accept or reject participation.

After the team members have completed individual reviews, they meet in an online, real-time conference to compare and discuss their evaluations. In the convergent participation model, reviewers first discuss the items showing the greatest inter-rater variability. The moderator can use statistics calculated by eLera to order items for discussion. To support comparison of evaluations, eLera presents an aggregated view of ratings and comments for each item of LORI (Figure 4).

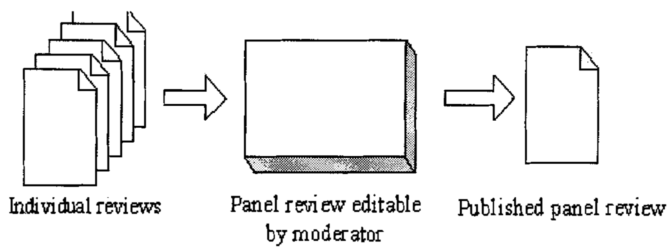


Figure 5: Individual reviews are merged to form a panel review that is published on the web.

Team members can edit their ratings and comments during the session. When the collaborative evaluation session is completed, the moderator publishes a team review by automatically aggregating individual reviews authored by team members. The tool requires the agreement of participants before incorporating their individual reviews in the team review. Figure 5 illustrates the process by which individual reviews are aggregated into panel reviews and published.

Translating across communities

Localization and translocalization of eLera

With the rapid growth of global e-commerce, localization issues are becoming a significant subject of research (Cyr & Trevor-Smith, 2004). The term localization is often used to connote the adaptation of a website to the language and culture of specific geographically or ethnically defined groups. However, our research is also concerned with translating terminology across communities of practice, such as high school biology teachers and e-learning professionals. Thus, we provide both linguistic and cultural localization of the eLera website such that users in different communities can share reviews without having to learn new terminology (Li, Nesbit, & Richards, 2006).

Localizing language

Over the last decade, the demographics of the web have seen a dramatic shift toward a more culturally diversified, multilingual user base. The proportion of users accessing the web in English dropped from 49.6% in 2000 (Haynes, 2002) to 35.6% in 2003 (Global-Reach, 2004). The proportion accessing the web in Asian languages (mainly Chinese, Japanese and Korean) increased from 20.6% in 2000 (Haynes, 2002) to 29.4% in 2003 (Global-Reach, 2004). Chinese-speaking web users, the second largest language group after English, increased from 1 million in 1997 to 160 million in 2004, and are expected to number 220 million by 2005 (Global-Reach, 2004).

We localized eLera to French and Chinese using the Zope localizer tool (David, 2004). Most eLera pages are composed of several elements from different sources, such as navigation menus, page body, and images with text. For every element of the web page, eLera determines which language it will be shown in. The determination is based on an ordered set of languages preferred by the user. If a user prefers French, but also knows some English, then the user can set his or her preference to [French, English]. eLera will show French by default, but if the element is not available in French it will display in English.

Chinese was selected because Chinese speaking users are the second largest language group on the web and have been relatively underserved by available content (Global-Reach, 2004; Netz-tipp, 2004). Table 2 shows that the ratio of web pages per user is far lower for Chinese than other major language groups on the web. Figure 6 shows a snapshot of the LORI form rendered in Chinese.

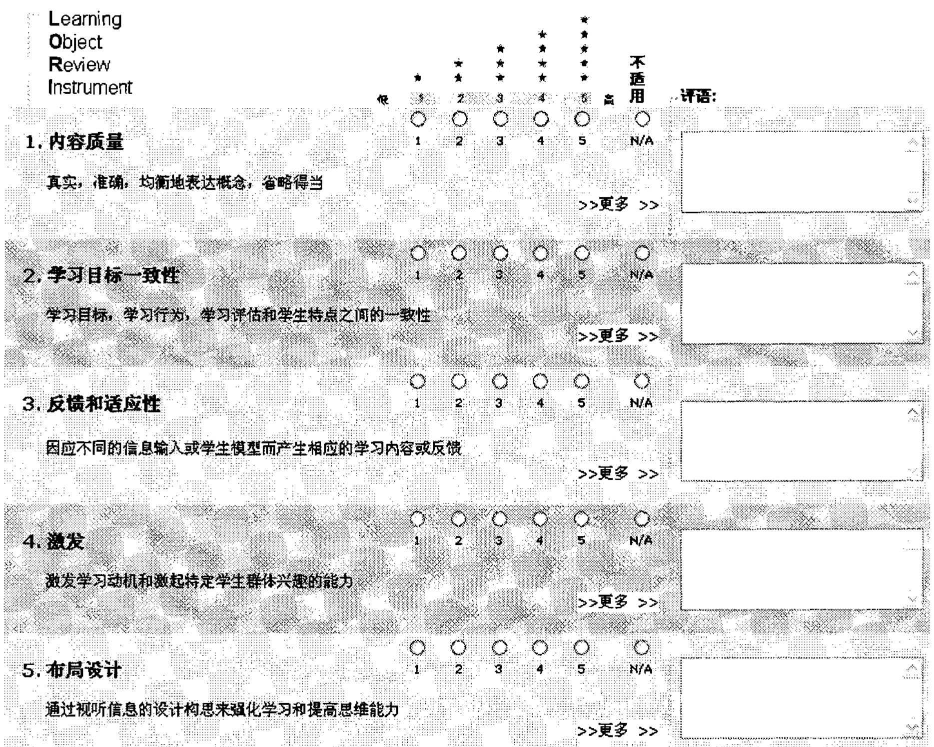


Figure 6: Chinese version of LORI (first five items only).

Table 1: Ratio of web pages to users for different language groups

Language	Web Pages (Millions)	Web Users (Millions)	Pages per User
English	11425	234	48.87
German	156	43	3.63
French	113	23	4.92
Chinese	48	78	0.62

With learning object metadata and reviews represented in multiple languages in the eLera database, how can users in one language community use the information generated by another language community? Standardized metadata presents a lesser problem because standard translations can be developed for all field names and fixed vocabulary values. We used the Canadian CanCore guidelines (Friesen et al., 2003) for mapping such metadata between English and French, and have extended this mapping to the Chinese E-Learning Technology Standard (CELTS) 3.1 (Xiang, Shen, Guo, & Shi, 2003).

Although numerical ratings require no translation, the evaluative comments entered by users do present a challenge. We are exploring a method in which reviewers are able, for each item of LORI, to select comments from a closed menu in addition to entering free text. Comments selected from menus would be automatically mapped to all supported languages.

Recommendation and trust

Through eLera one can research models for supporting e-learning communities of practice. This research asks how online communities should be structured to foster norms of reciprocity, collective action, identity, and information flow (Putnam, 2000). Key questions at this stage are: How can community members recommend resources and reviews to others? How can they find and be introduced to other members with similar or complementary interests? How can they build the identity, interpersonal trust and reputation that are prerequisites to effective collective activity?

At present, eLera provides only rudimentary facilities for recommendation and trust. By default, search results are ordered by average rating so that the most highly rated objects are presented at the top of the list. Users can also choose to order objects by *popularity*, a metric that is incremented whenever an object is placed in a personal collection. To support trust and alliance building, eLera members can create personal profiles detailing their interests and areas of expertise. Thus, decisions about whether to trust and collaborate with a reviewer can be based on the combined knowledge of his or her profile and previous reviews.

As we build on these features, we are researching more advanced models of trust and recommendation that will contribute to the nascent research base in this area (Nesbit & Winne, 2003; Recker, Walker, & Lawless, 2003; Recker & Walker, 2003; Wiley & Edwards, n.d.). For example, we are implementing a "web of trust" for eLera in which members can create a list of highly trusted others. eLera will be able to recommend new members for one's trust list by chaining forward through the network of trust lists.

In practice, eLera team has found the benefits and difficulties in sharing reviews and evaluations of learning resources across local education communities that have different local practice in education. It becomes clear that the interoperability issue becomes an increasingly important among communities of practice. In the next chapter, I discuss the issue of interoperability among domain ontologies.

CHAPTER 3.
INTEROPERABILITY AMONG DOMAIN ONTOLOGIES

Humans have a long history of using classification systems and taxonomies. Early classification systems can be seen in the categorization of organisms by thinkers such as Carolus Linnaeus (The Columbia Encyclopedia, 1985), Charles Darwin (Wikipedia, 2005) and Aristotle (the Utah State Office of Education, 2005). The original purpose of biological classification was to identify the relationships among organisms, and organize the huge number of known plants and animals into categories that could be named, remembered, and easily discussed.

Classification methods evolve with technological advances. For example, the early classification of organisms could be as simple as dividing animals into three groups according to how they moved: walking, flying, or swimming. Later systems, animals could be classified by macromolecular data, such as protein variation and nucleic acids. A classification system can be a natural system which reflects the relationships among organisms, or an artificial system which is based on categories assigned only for convenience, such as the classification of flowers by colour.

The classification of the natural world has laid the foundation for modern science. The modern library system is built on subject matter classification systems. Libraries organize their collections in a systematic way, so that books can be found quickly and easily. A library classification system "divides all knowledge into precise categories and subcategories. Each category is called a 'class' and each subcategory is called a 'division' or 'subdivision.'" (San Mateo County Community College District, 2005).

In 1872, Melvil Dewey invented the first major classification system used by libraries. Known as the Dewey Decimal System (Online Computer Library Center, 2005), it divides all knowledge into ten main classes numbered from 000 to 900; these ten primary classes are then split into divisions, which can be subdivided even further through the use of decimal numbers. It has been used in many libraries. Another classification system that has been used in many libraries is the Library of Congress Classification System. Devised in 1897, the Library of Congress Classification System (Library of Congress, 2005) is a highly detailed system that uses combinations of letters and numbers to represent subject areas. It divides all knowledge into 21 main classes indicated by a single letter of the alphabet. These main classes are broken into principal subdivisions by an added letter.

Library subject classification can become very complex when a book deals with more than one subject. A class may not necessarily include all the books on a given subject. Even one subject may cover more than one class. This complex relation can not be easily expressed by the existing classification system. Furthermore, people working in different domains have developed their own classification systems. Even in the same domain, there are multiple ways to classify the same resources.

The IEEE LOM classification descriptor allows repositories to adopt and specify any subject classification system. In fact, there are many different subject classification systems used in different repositories, the co-existence of multiple classification systems hampers the interoperability of learning object repositories and confuse users working across multiple repositories. It appears to be impossible to require all repositories and users to adopt a single standard classification system solution because school teachers, university instructors, instructional designers and students prefer to use familiar terms for subject matter, learning objectives, and achievement level, which have been established in a local community of practice. The problem, then, is how can one keep using one's own classification system, but still be able to search (digital) libraries based on the different classification systems?

Interoperation of Knowledge Domain Taxonomies Using Ontology Mappings

Interoperation of domain ontologies

With subject terms entered in a local ontology, how can users in one community (e.g., Ontario high school teachers) use the metadata generated by users in another community (e.g., French university professors)? One strategy is to adopt a core ontology such as the Library of Congress classification system as a universal subject taxonomy into which a large number of local subject taxonomies can be mapped. The development of local ontologies may be more challenging than expected. Indeed, in an effort to guide convergence of classifications the CanCore implementation guide cautions against the spurious development of local taxonomies (Friesen et al., 2003).

To link local repositories into an interoperable federation, the local taxonomies need to be mapped to higher order ontologies. Hatala and Richards (2004) proposed the "semantic cobblestone" concept, which enables local schemas to be articulated for interchange between search utilities. Just as a given object is usually designed for a particular area of content, audience and pedagogical strategy, it should be advantageous to map a given learning object to more than one classification scheme. Rich taxonomical information indicating the local learning outcomes, the local content descriptions, and the pedagogical design of the object would enrich the object descriptions and enable a wide range of future services related to the selection of learning objects for specific instructional contexts. The cobblestone approach would be particularly advantageous when mapping to a higher ontology results in a significant loss of local metadata.

Recent research in ontology mapping

Adaptation mappings involve modifying one domain knowledge to match the expectations, or requirements of another in order to achieve the task at hand. For example, Mid-continent Research for Education and Learning (McREL: Kendall, 2003) uses customized metadata schema to identify and retrieve learning resources by the learning objectives that these materials serve. The learning objective is a linkage that connects standards of all states that serve the same learning objectives. Therefore the learning resources can be mapped to every state standard that has embedded within them the same learning objective. Another example is the "Peace Repository" that was created for the Peace River North School District in BC (School District 60, 2005). In this repository, a resource is tagged with a local vocabulary, which allows for a simple search to return parts of resource, or the whole resource. Though this approach is conceptually direct and straightforward, there remains the problem that the system is specialized to the local context, and cannot be readily applied in other contexts.

To foster local learning resources exchange, we propose to use of ontology mapping techniques because ontologies are the best way to describe the semantics of the data such that the semantics provide a uniform way to make different parties to understand each other. We use domain ontologies to represent both subject taxonomies and subject classification systems, where a domain ontology can be seen as "an explicit list and organization of all the terms, relations and objects that constitute the representational scheme for that domain" (Gennari, Tu, Rothenfluh, & Musen, 2005). Subject taxonomies are ontologies in the sense that relations among the terms are not so critical, and ontologies have more expressive power in describing relations especially when the relations are multidimensional. Therefore, dealing with interoperability issues at the ontology level is more appropriate. Basically, we regard mapping as relating similar concepts or relations from different sources to each other by using different relations (Klein, 2001). Ontology mapping can be seen as "the process whereby two ontologies are semantically related at conceptual level, and the source ontology instances are transformed into the target ontology entities according to those semantic relations" (Silva & Rocha, 2003)

Research in ontology mapping is relevant and very close to the research in the field of schema (XML Schema and database) mappings. Shvaiko and Euzenat (2005) identified that the main commonalities between ontologies and schemas are that (a) they both provide a vocabulary of terms that describe a domain of interest and (b) they both constrain the meaning of terms used in the vocabulary. However, database schemas very often do not provide an explicit definition of the semantics for their data, while their semantics are usually specified explicitly at design-time. The semantics defined in such a way are frequently not a part of a database specification. Basically, it is up to the developer to discover the organization of schemas in order to determine the meaning of their data. For example, one can have trouble discovering the *is-a* (parent/child) relations among domain concepts from a database schema. On the other hand, ontologies are logical systems that obey some formal semantics, so that we can interpret ontology definitions as a set of logical axioms (e.g. subclass of relation). The same is true for the use of a mapping ontology, such as the Simple Knowledge Organization System (SKOS) Mapping vocabulary, compared to a look-up table in a database. Since the meanings of the mapping relation are defined in an (OWL) ontology, every semantic reasoner (e.g., OWLJessKB) can interpret those relations and provide a basis for the development of rules that make inferences about them.

Ontology mapping is a actively researched in areas such as federated repositories, data integration and the semantic web. Kalfoglou and Schorlemmer (2003b) has Categorized the works in this area into 9 categories: frameworks; methods and tools; translators; mediators; techniques; experience reports; theoretical frameworks; surveys; and examples. This categorization can help researchers to better understand the type of work in this area. To facilitate understanding the process of ontology mapping, Noy (2004) suggests using three-dimensions: *mapping discovery*, which concerns how to find and determine similarities between the two given ontologies; *declarative formal representations of mappings*, which is concerned with mapping representations between two given ontologies; and *reasoning with mappings*, which is about execution of mappings.

There are some major related projects that can be seen as paradigmatic approaches in ontology mapping. In the following section, four ontology mapping projects are discussed with regard to the criteria motioned earlier.

Mapping Domains to Methods

Park, Gennari and Musen (1998) developed a framework to conceptualize the binding of the domain-knowledge base and method components as generating mappings between concepts in the domain and analogous concepts in the method's universe of discourse. Protégé was used as tool to create a *mapping ontology*, which defines the types of possible transformations under the system; different types of *mapping relations* were identified manually by this mapping ontology, depending on the complexity of the transformation, it ranged from simple copy to functional transformations. At run-time, the *mapping interpreter*, which implemented the mapping types of the mapping ontology, scans for matching instances from the domain classes and creates corresponding method instances.

OntoMerge

The OntoMerge (Dou, McDermott & Qi, 2005) is an ontology translation tool, it merges ontologies by taking the union of the terms and the axioms that define them. Bridging axioms that describe mappings between ontologies are added manually by experts to relate the concepts between the two ontologies. Merged ontologies that contain symbols, facts and bridging axioms constitute an ontology that can be further merged with other ontologies. OntoEngine works as an inference engine on the merged ontology to enable translation between mapped ontologies. It runs either in forward chaining or backward-chaining mode depending on the task at hand.

MAFRA

MAFRA (Maedche, Motik, Silva, & Volz, 2002) is an ontology mapping framework that prescribes all phases of the ontology mapping process, including analysis, specification, representation, execution and evolution. It uses the declarative representation approach in ontology mapping by creating a *Semantic Bridging Ontology (SBO)* that contains all concept mappings and associated transformation rule information. MAFRA also relies on domain experts to predetermine the mapping relations between two ontologies, the information is encoded into concepts in SBO, which serves as an upper ontology to govern the mapping and transformation between two ontologies. Each concept in SBO consists of five dimensions: *entity*, *cardinality*, *structural*, *constraint* and *transformation*. During the process of ontology mapping, a software agent will inspect the values from two given ontologies under these dimensions and execute the transformation process when constraints are satisfied.

IF-Map

The IF-Map (Kalfoglou & Schorlemmer, 2003a) is an ontology-mapping method based on information-flow theory. The system identifies mappings automatically based on the theory of information flow. There are four steps for the automatic generation of mappings between ontologies: ontology harvesting; translation; infomorphism generation; display of results. Infomorphisms contain all the mapping relations between, ontologies. Since these mapping relations are in RDF format, they can be inferred by Semantic Web applications.

Ontology technology has been recognized as a formal way to represent a shared conceptualization of a domain (Gruber, 1993), and it has already been applied to many e-learning systems (Sampson, Lytras, Wagner, & Diaz, 2004). However, very few of them provide a solution for the problem of interoperating e-learning systems that are based on different ontologies (Kalfoglou, Hu, & Reynolds, 2005). Considering that many ontologies have so far been developed in the domain of web-based educational systems, Kalfoglou et al. (2005) emphasize the importance of ontology mappings, as a means for semantic interoperability among different ontologies.

The generation of mapping relations is the core of ontology mapping. So far, mappings between two ontoloies are generated either by ontology experts or by automatic tools. Automating the process of ontology mapping, to save time and offer guidance to ontology experts, is an active area of research. There are many tools available for automatic or semi-automatic mapping; although Dou et al. (2005) argued that automatic mapping tool cannot generate 100% accurate mappings and the result needs manual correction by ontology experts.

In our approach to ontology mapping, we use a mapping ontology, an ontology containing classes and properties (i.e. primitives), that can express relations between ontology concepts and properties. Mapping relations in our case are predefined by ontology experts. I did not use any formal tool to build those ontologies, and they are all built by using a simple text editor; but it is suggested that Protégé is efficient tool for build domain ontologies.

In the following section, I will discuss in detail the ontology mapping design and implementation in eLera.

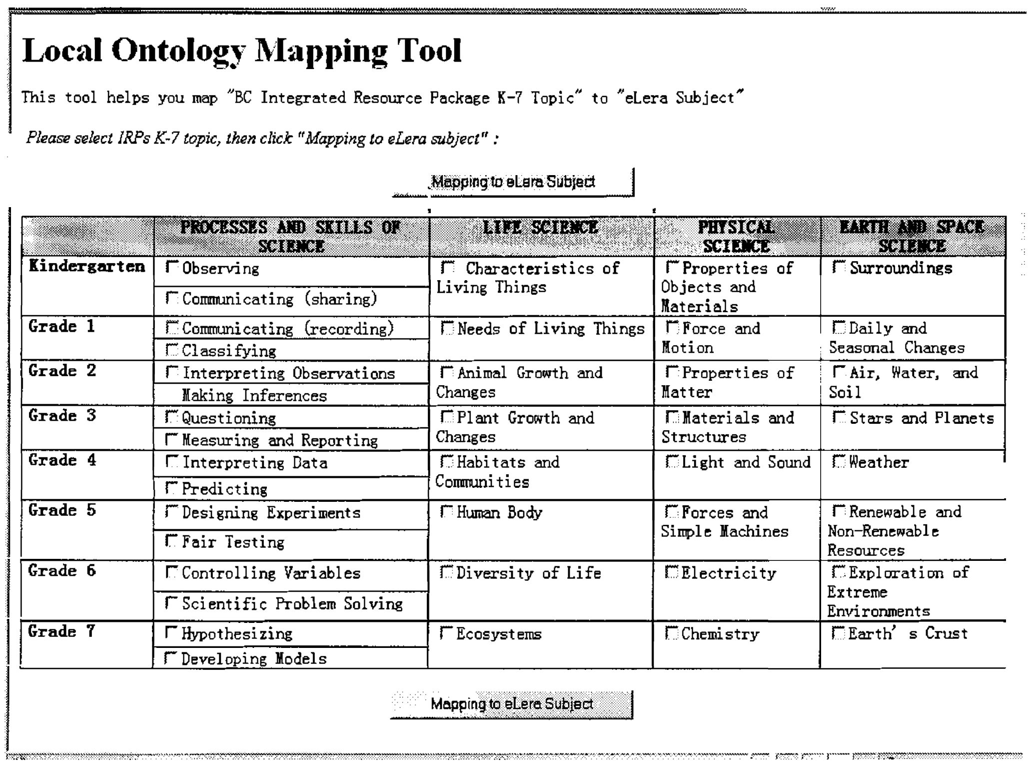
Ontology Mapping Design and Implementation in eLera

In Canada, each of the ten provinces has separate learning outcomes established for a given subject in the K-12 public education system. In British Columbia (BC), the Ministry of Education has developed learning resources for K-12 known as Integrated

Resource Packages (IRPs). The IRPs consist of the provincially required curriculum, suggested ideas for instruction, a list of recommended learning resources (books, videos, electronic resources, etc.), and possible methods for teachers to use in evaluating students' progress (BC Ministry of Education, 2005). Similarly, in the United States each state has its own set of learning outcomes. It has also been observed that while the learning outcomes in sciences and mathematics are reasonably concrete and well-ordered, learning outcomes for the arts and humanities can be much more conceptual and abstract in nature. Ultimately, the selection of local taxonomies might be most pragmatically based on the local syllabus used daily by classroom teachers in combination with a simple model of pedagogical approaches.

Taxonomical information indicating the local learning outcomes, the local content descriptions, and the pedagogical design of the object would enrich the object descriptions and enable a wide range of services related to the selection of learning objects for specific instructional contexts. In our research, a modified DDC, called eLera-DDC, is used as a general taxonomy into which a large number of local ontologies can be mapped. For example, Figure 7 shows an eLera interface in which a British Columbia school teacher can choose a BC Integrated Resource Package (IRP) topic, a user can choose a BC IRP topic for the subject field (Figure 8). A user can click the check box beside each topic and then click submit button, the eLera search engine transforms those concepts into eLera-DDC compliant queries using ontology mapping, which will return learning object records that match the criteria in the eLera database. Furthermore, the search can be done in other repositories through the Internet, e.g. using EduSource

Communication Layer (ECL) to carry out a federated search (Hatala et al., 2003). Figure 9 illustrates how a local group searches learning objects by local taxonomies.



	PROCESSES AND SKILLS OF SCIENCE	LIFE SCIENCE	PHYSICAL SCIENCE	EARTH AND SPACE SCIENCE
Kindergarten	Observing Communicating (sharing)	Characteristics of Living Things	Properties of Objects and Materials	Surroundings
Grade 1	Communicating (recording) Classifying	Needs of Living Things	Force and Motion	Daily and Seasonal Changes
Grade 2	Interpreting Observations Making Inferences	Animal Growth and Changes	Properties of Matter	Air, Water, and Soil
Grade 3	Questioning Measuring and Reporting	Plant Growth and Changes	Materials and Structures	Stars and Planets
Grade 4	Interpreting Data Predicting	Habitats and Communities	Light and Sound	Weather
Grade 5	Designing Experiments Fair Testing	Human Body	Forces and Simple Machines	Renewable and Non-Renewable Resources
Grade 6	Controlling Variables Scientific Problem Solving	Diversity of Life	Electricity	Exploration of Extreme Environments
Grade 7	Hypothesizing Developing Models	Ecosystems	Chemistry	Earth' s Crust

Figure 7: The eLera interface in which a British Columbia school teacher can choose a BC Instructional Resource Package (IRP) topic

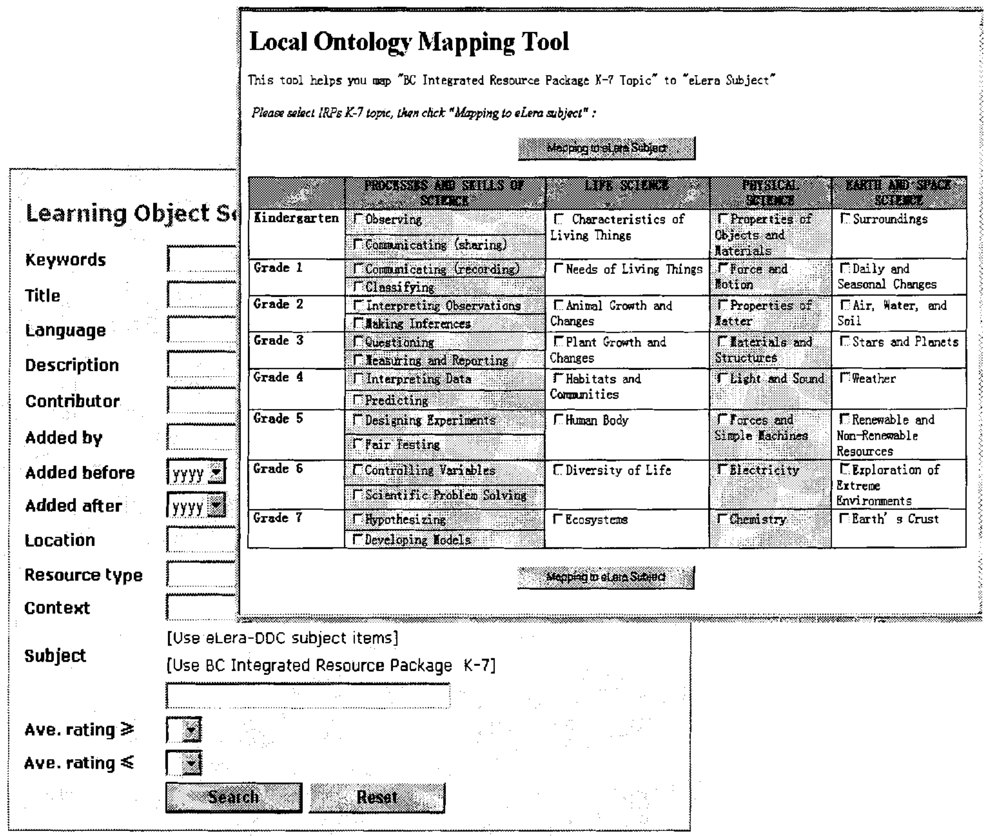


Figure 8: A screen shot showing the search interfaces in eLera where a BC school teacher can choose a BC IRP topic for the subject field in order to find a learning object that matches the selected topic.

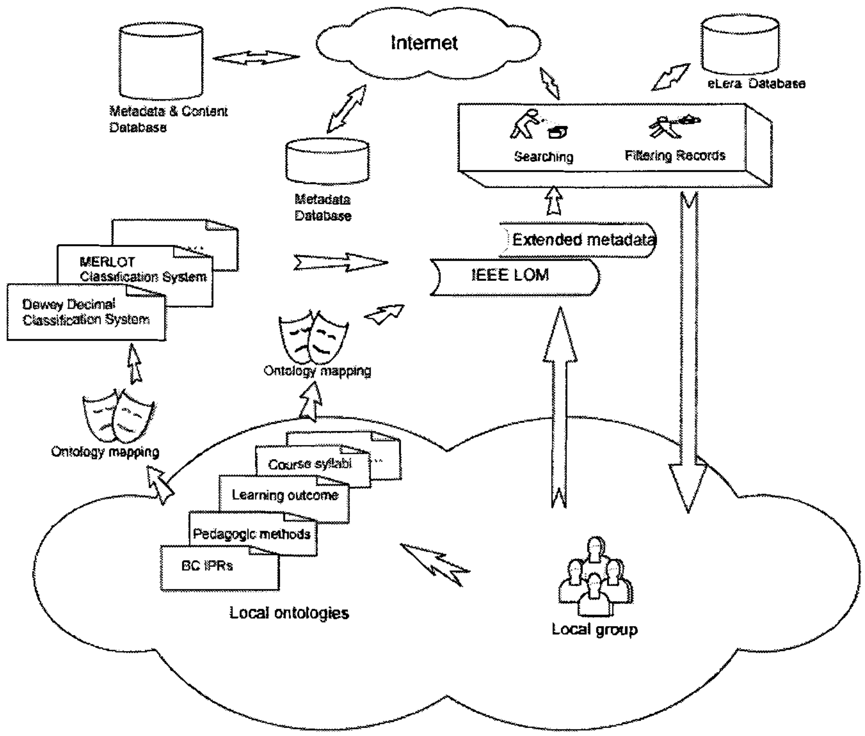


Figure 9: A local group searches learning objects by local taxonomies

Simple knowledge organization system (SKOS)

We use the Simple Knowledge Organization System (SKOS) for defining different types of ontologies (e.g. classifications, taxonomies, thesaurus, and curriculum) as well as mappings among different domain ontologies (Miles & Brickley, 2005). SKOS is a recent W3C RDF-based effort developing specifications and standards that support the use of knowledge organization systems such as thesauri, classification schemes, subject heading lists, taxonomies, terminologies, glossaries and other types of controlled vocabulary within the framework of the Semantic Web (W3C, 2004). The SKOS consists of three RDF vocabularies that are still under active development at the W3C:

- *SKOS Core* for expressing the basic structure and content of concept schemes (taxonomies, terminologies);
- *SKOS Mapping* for describing mappings between concept schemes (*broadMatch, narrowMatch, exactMatch, majorMatch, minorMatch*);
- *SKOS Extension* containing extensions to the SKOS Core useful for specialized applications.

In Figure 10 we give excerpts of two ontologies defined in SKOS. Figure 10a shows a snippet of the ontology based on BC IRP, while Figure 10b contains a part of the eLera-DDC. Figure 10c exemplifies the use of the SKOS Mapping vocabulary defining mappings between the BC IRP and eLera-DDC ontologies.

a)
```
<rdf:RDF>
 <skos:ConceptScheme rdf:ID="IRP-Science">
   <skos:hasTopConcept rdf:resource="PSS"/>
   <skos:hasTopConcept rdf:resource="LS"/>
   <skos:hasTopConcept rdf:resource="PS"/>
   <skos:hasTopConcept rdf:resource="ESS"/>
 </skos:ConceptScheme>

 <skos:Concept rdf:ID="PSS">
  <skos:prefLabel xml:lang="en">Processes and Skills of
    Science</skos:prefLabel>
  <skos:inScheme rdf:resource="IRP-Science"/>
  <skos:narrowerGeneric rdf:resource="PSS1"/>
  <!--...-->
  <skos:narrowerGeneric rdf:resource="PSS16"/>
 </skos:Concept>

 <skos:Concept rdf:ID="PSS1">
  <skos:prefLabel xml:lang="en">Observing</skos:prefLabel>
  <skos:inScheme rdf:resource="IRP-Science"/>
  <skos:broaderGeneric rdf:resource="PSS"/>
 </skos:Concept>

 <skos:Concept rdf:ID="LS">
  <skos:prefLabel xml:lang="en">Life Science</skos:prefLabel>
  <!-...-->
 </skos:Concept>
 <!--...-->
</rdf:RDF>
```

b)
```
<rdf:RDF>
 <skos:ConceptScheme rdf:ID="elera">
   <skos:hasTopConcept rdf:resource="E600"/>
   <!- ...-->
   <skos:hasTopConcept rdf:resource="E500"/>
 </skos:ConceptScheme>

 <skos:Concept rdf:ID="E500">
   <skos:prefLabel xml:lang="en">Science</skos:prefLabel>
   <skos:inScheme rdf:resource="elera"/>
   <skos:narrowerGeneric rdf:resource="E550"/>
   <!-...->
   <skos:narrowerGeneric rdf:resource="E547"/>
 </skos:Concept>

 <skos:Concept rdf:ID="E570">
   <skos:prefLabel xml:lang="en">Biology and
   Life Sciences</skos:prefLabel>
   <skos:inScheme rdf:resource="elera"/>
   <skos:broaderGeneric rdf:resource="E500"/>
 </skos:Concept>

 <skos:Concept rdf:ID="E577">
   <skos:prefLabel xml:lang="en">Ecology</skos:prefLabel>
   <skos:inScheme rdf:resource="elera"/>
   <skos:broaderGeneric rdf:resource="E500"/>
 </skos:Concept>
 <!--...-->
</rdf:RDF>
```

c)
```
<rdf:RDF>
 <!-PSS1 PROCESSES AND SKILLS OF
 SCIENCE::Observing -> eLera DDC:Science -->
 <skos:Concept rdf:about="&IRP;PSS1">
  <map:majorMatch>
        <skos:Concept rdf:about= "&elera;E500"/>
  </map:majorMatch>
 </skos:Concept>

 <!-LS1 LIFE SCIENCE::Characteristics of
 Living Things -> eLera DDC:Ecology -->
 <skos:Concept rdf:about="&IRP;LS1">
  <map:minorMatch>
   <skos:Concept rdf:about= "&elera;E577"/>
  </map:minorMatch>
 </skos:Concept>
 <!--...-->
</rdf:RDF>
```

Figure 10: The RDF/XML snippets of the SKOS based ontologies used in this thesis. (a) A part of the topics in British Columbia Integrated Resource Packages (BC IRP); (b) An excerpt of the eLera-Dewey Decimal Classification (DDC); (c) An excerpt of mappings between BC-IRP and eLera encoded using the SKOS Mappings vocabulary

Mapping interpreter

A reviewer/searcher uses the local ontology through the eLera interface that has a back end encoded in SKOS as well as a utility to match RDF/XML expressions of different ontologies. In order to employ SKOS-defined ontologies as well as to interpret mapping relations we use the search algorithm developed by Gašević and Hatala (2006). The algorithm takes a concept from the source ontology (i.e., BC IRP) as an argument to search for concepts in the target ontology (i.e., eLera-DDC) based on the SKOS mapping relations defined between these ontologies. That way, the algorithm generates a sequence of concepts compliant with the eLera-DDC that the eLera learning object repository can interpret when searching for learning objects. Note that the algorithm uses all the children of matched concepts in the eLera-DDC ontology regardless their depth level. The search algorithm also solves the case when there are no mappings defined for the query argument. To overcome this issue the algorithm looks for both child and parent concepts of the query argument in the BC IRP ontology that have defined mappings with the eLera-DDC ontology. Finally, the algorithm sorts the generated sequence of eLera-DDC concepts taking into account both their depth level and mapping relations with the target ontology. The algorithm uses the Jess rule-based reasoning engine to perform mappings as well OWLJessKB to convert SKOS (RDF-based) ontologies (and mappings) into the Jess facts.

The deployment of the ontology mapping search algorithm on the eLera system is shown in Figure 11. When a request comes from a user who uses selected local ontology (in our case BC IRP), the system translates the query argument to eLera-DDC ontology in run time. Then eLera generates an SQL query to search its learning object repository.

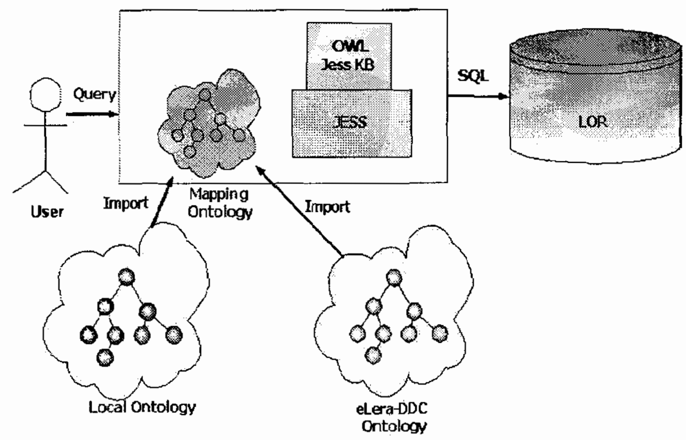


Figure 11: Using SKOS-based ontologies and ontology mappings in the eLera system.

As reported in Chapter 4, the ontology mapping system in eLera was evaluated by *Recall* and *Precision,* which are standard measures in Information Retrieval (IR). The system was also evaluated by a program of usability testing discussed in Chapter 5.

CHAPTER 4.
INFORMATION RETRIEVAL EVALUATION OF ONTOLOGY MAPPING

Information needs are diverse. Individual users are interested in different things. In some cases, such as in legal research, a lawyer wants to do an exhaustive search to find all the relevant cases. In other cases, however, such as a typical search with Google, only a small fraction of the returned results is "good enough." Often users hardly browse the results beyond the first three result pages because the returned results in these pages contain results good enough to serve their purpose. In retrieving learning resources, teachers, instructional designers, or students are likely only interested in "good enough" results, though what is "good enough" will vary across users. We assume that the top 30 returned results (or returned results in the first three pages) contribute the most to the "good enough" results in retrieving learning objects. Therefore, in this evaluation we examined the accuracy of retrieval up to the top 30 returned search results.

With ontology mapping, IRP topics can be used as *subject search* to retrieve learning objects that match the topics, while before, a user had to use *keyword search*. In this chapter, subject search, which uses local ontology mapping, is compared with simple keyword search. The main purpose is to discover which method produces more accurate search results as determined by recall-precision data under the assumption that a search method shows better performance if its precision is higher than others at the same recall level.

Method

Recall and *Precision* are standard measures in Information Retrieval (IR). Recall is the fraction of the relevant documents which were retrieved. Precision is the fraction of the retrieved documents which are relevant (Baeza-Yates & Ribeiro-Neto, 1999). Consider the cells of Table 2 representing the number of documents which are retrieved (or not) and relevant (or not). The symbol A, for instance, represents the number of relevant documents which were retrieved.

Table 2: Table 2: Symbols A, B, C, and D Represent the Number of Documents which are Retrieved (or Not) and Relevant (or Not)

	Relevant	**Irrelevant**
Retrieved	A	B
Not retrieved	C	D

The symbols identified in Table 2 are used to mathematically define the concepts of precision and recall:

$$\text{Precision} = |A| / (|A|+|B|)$$

$$\text{Recall} = |A| / (|A|+|C|)$$

A recall-precision graph shows the trade-off between recall and precision, and reflects system performance at multiple operating points. If the precision over the first K documents returned (d_K) is considered for K = 1, 2, ... , then the precision goes up every time d_K is relevant and down every time it is irrelevant, but on the whole, precision tends to go down, so there is a trade-off between recall and precision as more documents are collected.

Measuring recall involves identifying *relevance* which is usually somewhat difficult. According to Davis (2006), it can be examined by the following criteria:

- Relevance to query as stated;
- Relevance to actual user question;
- Interest to user after the fact;
- Originality: New information contained (depends on other docs retrieved);
- Authority: User has confidence in information contained.

Our criterion for relevance is defined as follows: A learning object is relevant if it contains some topical content that relates to the selected IRP topic. It is not relevant if it does not contain any content relevant to the selected BC IRP topic. For example, for the IRP topic "Grade 5 Life Science: Human Body" , the learning object "Map of the Human Heart"(http://www.pbs.org/wgbh/nova/heart/ heartmap.html), which shows an animation of heart function, is relevant; but learning object "Half-Life Gizmo" (http://gizmos.explorelearning.com/science/half-life/), which graphically shows radioactive decay, is not relevant since the content is irrelevant.

Relevance is measured by clicking through each link. The learning object is irrelevant if the following failures and errors occur:

- No information on Web
- Incorrect/outdated information
- URL out of date (document moved)

- Dead link
- Page cannot be downloaded
- Page cannot be correctly displayed
- Page unsuitable to user (too advanced, or too elementary).

What objects were used?

The comparison between keyword search and subject search was done by using selected BC IRP topics in the eLera database.

Each BC IRP topic has a label, for example, Grade 7 Life Science is labelled as "Ecosystems," and Grade 4 Physical Science is labelled as "Light and Sound." The label was used as the keyword for keyword search and then the retrieved records were compared with those by the same BC IRP topic that was mapped to the eLera-DDC subjects and used as the subject search, while all other search criteria are the same. For example, Grade 7 Life Science is labelled as *ecosystems*, ecosystems is used as the keyword for keyword search, and then Grade 7 Life Science is mapped to *ecology* in the eLera-DDC subjects, the ecology subject is selected in the subject search, and then results by both methods are compared.

How were they selected and recall-precision measured?

Since the number of keywords used in a keyword search greatly affects the number of retrieved records, I used single and multiple keywords in the evaluation.

In the case where only one keyword was used, the BC IRP theme *Grade 7 Life Science* was selected. This topic was labelled as ecosystems, and therefore, it was used as the single keyword for the keyword search. For the subject search, ecosystems was mapped to the eLera-DDC subject ecology, which was used in the subject search.

In the case of multiple keyword search, the BC IRP theme *Grade 6 Life Science* was selected. This topic was labelled as *Diversity of Life*, and therefore multiple keywords (diversity, life) were used as keywords with the "*or*" and "*and*" operators in the keyword search. For the subject search, Diversity of Life is mapped to the eLera-DDC subject microorganisms which was used as the subject search term, and then a combination of keyword and subject is used for retrieval.

Checking points are selected as the top five, ten, fifteen, twenty, twenty-five, and thirty retrieved records. Recall and precision were calculated at each checking point for the searches (keyword, subject, and combined search), and a recall-precision graph was generated based on those data to compare the performance at different points. For example, if six relevant documents are found in the top 10 retrieved records, suppose there are 40 relevant documents in the whole documents set, then the recall at this checking point is 6÷40=0.15 and precision is 6÷10=0.6. If the retrieved records are less than the selected checking point, then the recall and precision will not be calculated at that checking point.

Results

In case of multiple keywords, Table 3 shows the recall-precision values calculated and number of relevant documents found at each checking point. Figure 12 shows that subject search has higher precision than keyword search using the *and* operator when the recall is above 28%, and has similar precision when the recall is below the 28% level.

Subject search has higher precision than keyword search using the *or* operator at all recall levels. Keyword search using the *and* operator produces higher precision than that of keyword search using the *or* operator.

Table 3: IR Evaluation with Multiple Keywords

Search method	retrieved records at different checking point	relevant	Recall	Precision
Subject search:	5	5	13.89	100.00
	10	9	25.00	90.00
	15	14	38.89	93.33
	20	19	52.78	95.00
	25	21	58.33	84.00
	30	24	66.67	80.00
Key words search using "and" operator	5	5	13.89	100.00
	10	9	25.00	90.00
	15	11	30.56	73.33
	20	13	36.11	65.00
	25	17	47.22	68.00
Key words search using "or" operator	5	1	2.78	20.00
	10	3	8.33	30.00
	15	8	22.22	53.33
	20	12	33.33	60.00
	25	14	38.89	56.00
	30	18	50.00	60.00
	10	9	25.00	90.00
	15	13	36.11	86.67

Note: Search was conducted at 2006-01-19 9:00 pm
Total records in eLera database: 242
Total relevant learning objects: 36

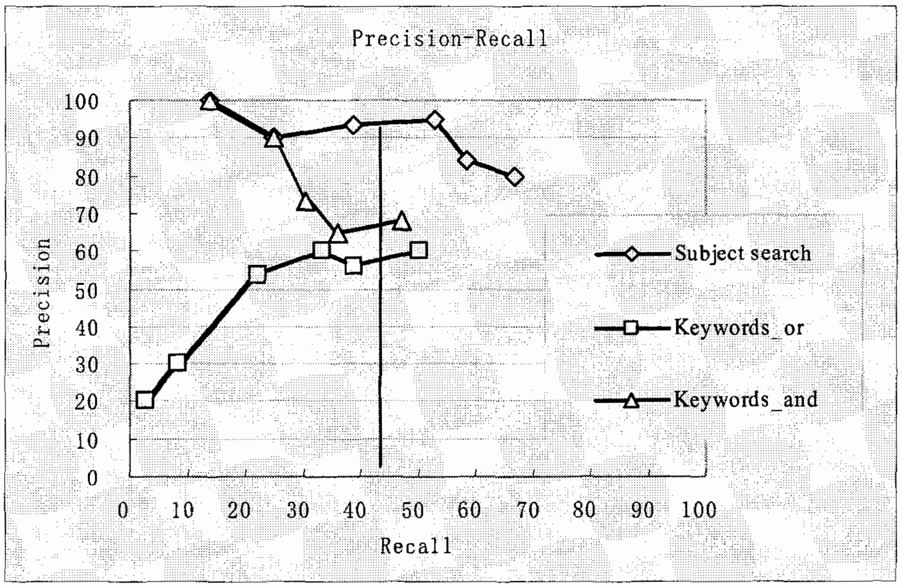


Figure 12: Precision-recall diagram shows a comparison of different search methods for multiple keywords.

In the simplest case, search uses only one keyword. Table 4 shows the recall-precision values calculated and number of relevant documents found at each checking point. It can be seen from Figure 13 that subject search has higher precision than keyword search when the recall is above 30%, and has similar precision when recall is below 30%.

Considering keyword and subject search in both cases (single keyword and multiple keywords), subject search shows better performance in terms of precision level. Finally, combination of search methods (keyword and subject search) produces higher precision.

Table 4: IR Evaluation with Single Keyword

Search method	Retrieved records at different checking point	Relevant	Recall	Precision
Subject search:	5	5	14.29	100.00
	10	10	28.57	100.00
	15	13	37.14	86.67
	20	15	42.86	75.00
	25	18	51.43	72.00
	30	20	57.14	66.67
	35	25	71.43	71.43
	40	29	82.86	72.50
	45	33	94.29	73.33
Key words search	5	5	14.29	100.00
	10	10	28.57	100.00
	15	12	34.29	80.00
	20	15	42.86	75.00
Combine Subject and Keyword search	5	5	14.71	100.00
	10	10	29.41	100.00
	15	14	41.18	93.33
	17	16	47.06	94.12

Note: Search was conducted at 2006-01-19 9:00 pm
Total records in eLera database: 242
Total relevant learning objects: 35

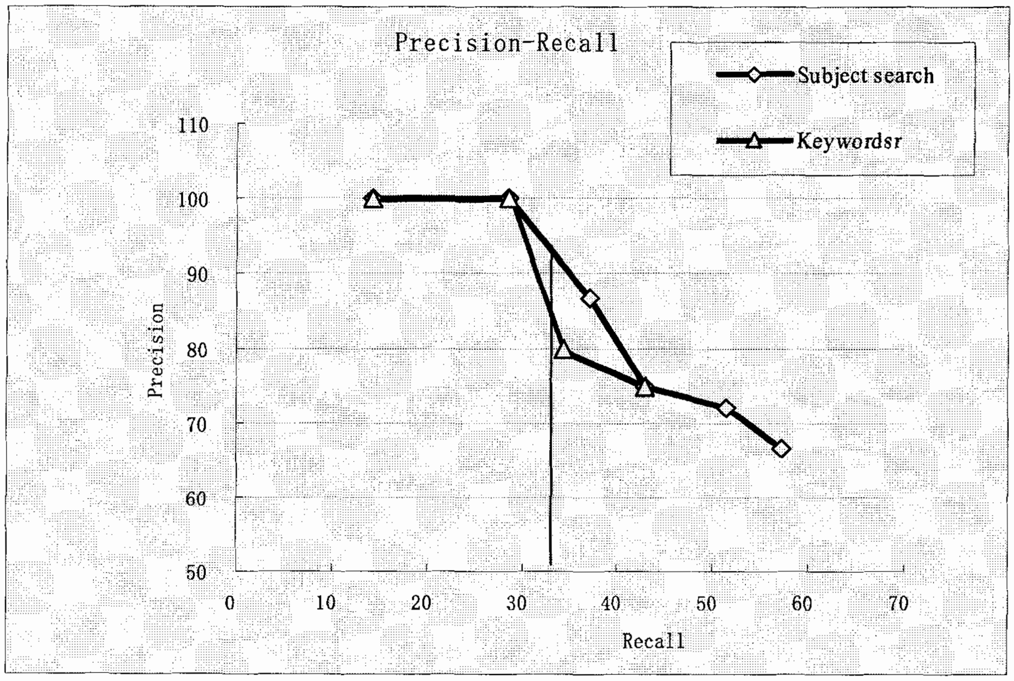


Figure 13: Precision-recall diagram shows a comparison of different search methods for single keywords.

Discussion of Information Retrieval Evaluation

In this information retrieval evaluation, we tested the system performance on two types of search: keyword search and subject search with ontology mapping. With ontology mapping, a user can use a local term, such as BC IRP topics to retrieve learning resources by conducting a subject search in a repository that uses a different classification system, which was not possible before. The above findings indicated that subject search produced equal or better quality retrieval of learning objects at different check points (single keyword and multiple keywords). Keyword search was shown to have limitations. For example, using ecosystems as a keyword will not retrieve learning objects tagged with terms such as ecology or bionomics. Using subject search, however, the term ecology used as a subject will return all the learning objects in the same subject area. Furthermore, an IRP topic may cover more than one eLera-DDC subject area. For example, Grade 2 Life Science is related to the eLera-DDC subjects animals (zoology) and ecology. Therefore, through mapping to subjects, learning objects in both subject areas can be retrieved.

In addition, this evaluation could be more persuasive if it were carried out on a major repository, so that a random selection of local terms can be used to compare the search results by the two methods. The result will be even more interesting if the repository is supported by a review system. Reviewers' rating could be used to rank the relevance of retrieved learning objects, so that the quality of the retrieved learning objects could be compared easily.

The overall findings in this evaluation have shown that the invention of the ontology mapping approach is significant since it enables a system to accept local terms and retrieve more relevant objects. In the next chapter, we will present the usability evaluation of the ontology mapping interface. The users' perspectives are an important complement of the retrieval evaluation.

CHAPTER 5.
USABILITY EVALUATION OF ONTOLOGY MAPPING

The implementation of ontology mapping described in chapters 3 and 4 enables school teachers to work with learning objects by local subject terms, specifically, the BC IRP topics with which they are already familiar. The usability evaluation reported in this chapter compares, from the users' point of view, subject search using BC IRP topics with keyword search.

Usability is defined by the International Organization for Standardization (ISO) as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO, 1998, part 11). The usability evaluation of a software application is focused on the user, not on the software itself, and it is determined by collecting data on users' interactions with the software, and users' resulting perception of the software's quality. Usability can be assessed and measured by how easy the software is to learn and use, how quickly a task is performed, how satisfied people are who perform the task, and so on. Usability testing is a "process that involves live feedback from actual users performing real tasks" (Barnum, 2002, p. 9). It is distinct from quality assurance, function testing, and reliability testing.

Usability testing as a research tool, depending on the objectives, time available, and resources, can range from a quantitative approach characterized by large sample sizes, complex test designs, and expensive lab setup, to less-formal qualitative studies with only a few participants. In this research, an online survey method was chosen, and usability evaluation was based on the following criteria.

Effectiveness is the accuracy and completeness with which users can achieve their goals. Measures of effectiveness include:

- percent of users able to successfully complete the task;
- objective measure of quality of output;
- objective measure of quantity of output.

Efficiency is the amount of effort users need to put in to achieve their goals. Measures of efficiency include:

- time to execute a particular set of instructions;
- average time to perform the task.

Satisfaction is how users feel about the system. Assessments of satisfaction include:

- the average score that participants give to rate the subject search as more prefered than keyword search on a 10-point scale;
- participants' additional comments.

Method

Participants

Ideally, "real users" such as teachers, instructional designers, and school students should be the participants, however, due to the constraints on time and availability of participants, students and instructors at Simon Fraser University were invited by email or by phone. A total of 21 people participated in the usability evaluation. Among those participants, there were two teachers, eight researchers, eleven students, and one person with another occupation.

Task

The Bucket Buddies Project is a live project created by the Center for Innovation in Engineering and Science Education (2005) and it joins students of environmental study from the United States and around the world. Students are instructed to collect samples from local ponds, and investigate if the organisms found in pond water are the same all over the world. This project is suitable for the grade 2 British Columbia curriculum in Life Science: Animal Growth and Changes. It was therefore chosen as an authentic educational application suitable for the usability survey. All instructions were provided online within the survey materials.

Materials

An online survey was created on a research server hosted by SFU Surrey. The survey module was customized from the tiki-wiki survey module, which is coded with PHP and runs on an Apache server with a backend mySQL database to collect the survey data.

The general instructions provided at the beginning of the survey are shown in Figure 14. The survey collected data anonymously. Participants entered no information that could be used to identify them.

Usability Survey on Searching Methods for Online Learning Resources

General Instructions:

In this survey, you will not be asked to input any of your personal information, such as name, age, sex etc. By clicking the survey questions, you consent that your survey data will be collected anonymously to support this research. You can discontinue your participation at any time. Any complains about this survey can be sent to the Director of SIAT, Dr. John Bowes at john_bowes@sfu.ca.

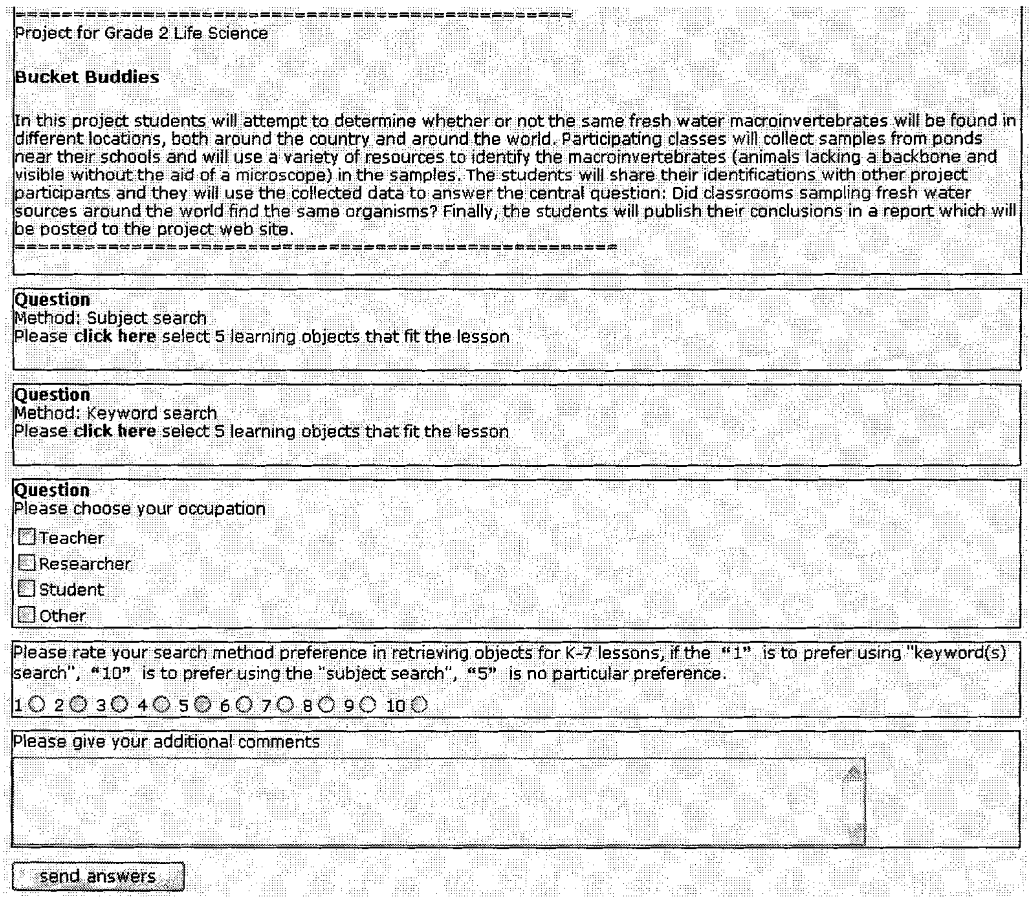
- In searching online leaning resources, there two popular methods: keyword search and subject search. Purpose of this survey is to compare those two approaches to see which one is more efficient and returns better results in retrieving objects for BC K-7 science lessons.
- Your task is to select five appropriate learning objects by each method in eLera database which fit the lesson, in other words, they can be used as reference materials for students in the project below.
- A summary of survey result can be found Here

If you have any question, please do not hesitate to contact jerryli@sfu.ca;
Thanks a lot for your help.

==

Figure 14: Instructions for the usability survey

Five questions, shown in Figure 15, were created to meet the goals of the usability survey. To avoid bias that might be induced by the sequence of the questions, the order of the keyword search and subject search questions alternated randomly.


Project for Grade 2 Life Science

Bucket Buddies

In this project students will attempt to determine whether or not the same fresh water macroinvertebrates will be found in different locations, both around the country and around the world. Participating classes will collect samples from ponds near their schools and will use a variety of resources to identify the macroinvertebrates (animals lacking a backbone and visible without the aid of a microscope) in the samples. The students will share their identifications with other project participants and they will use the collected data to answer the central question: Did classrooms sampling fresh water sources around the world find the same organisms? Finally, the students will publish their conclusions in a report which will be posted to the project web site.

Question
Method: Subject search
Please **click here** select 5 learning objects that fit the lesson

Question
Method: Keyword search
Please **click here** select 5 learning objects that fit the lesson

Question
Please choose your occupation
- Teacher
- Researcher
- Student
- Other

Please rate your search method preference in retrieving objects for K-7 lessons, if the "1" is to prefer using "keyword(s) search", "10" is to prefer using the "subject search", "5" is no particular preference.
1 2 3 4 5 6 7 8 9 10

Please give your additional comments

send answers

Figure 15: Survey questions

Keyword search procedure

Each participant was required to select ten learning objects that fit the Bucket Buddies lesson, five using subject search, and five using keyword search. There were instructions for each search method. When tasked to perform a keyword search, the participant was presented with the keyword search instructions shown in Figure 16.

To complete the keyword search task, participants were required to generate suitable keywords. Once the keywords were submitted, a result screen listed all the results (see Figure 17).

Users were instructed to browse the results and choose five learning objects which fit the lesson, and then submit them. A timer was employed to record the time each user spent in finding the five learning objects. Average duration was recorded for each learning object.

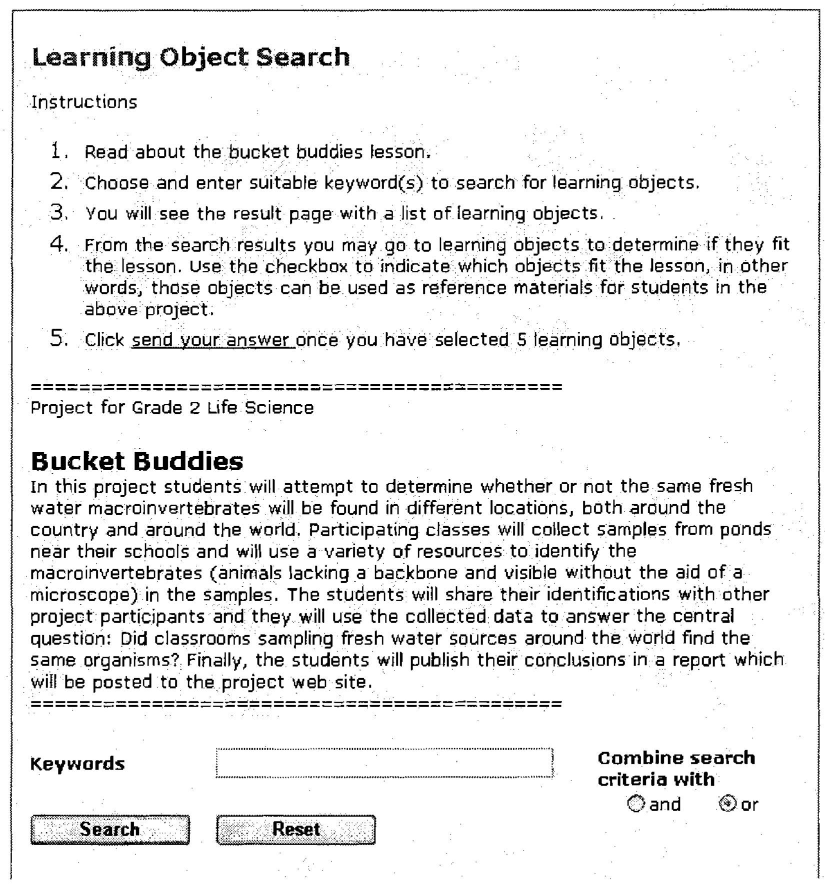


Figure 16: User interface for keyword search

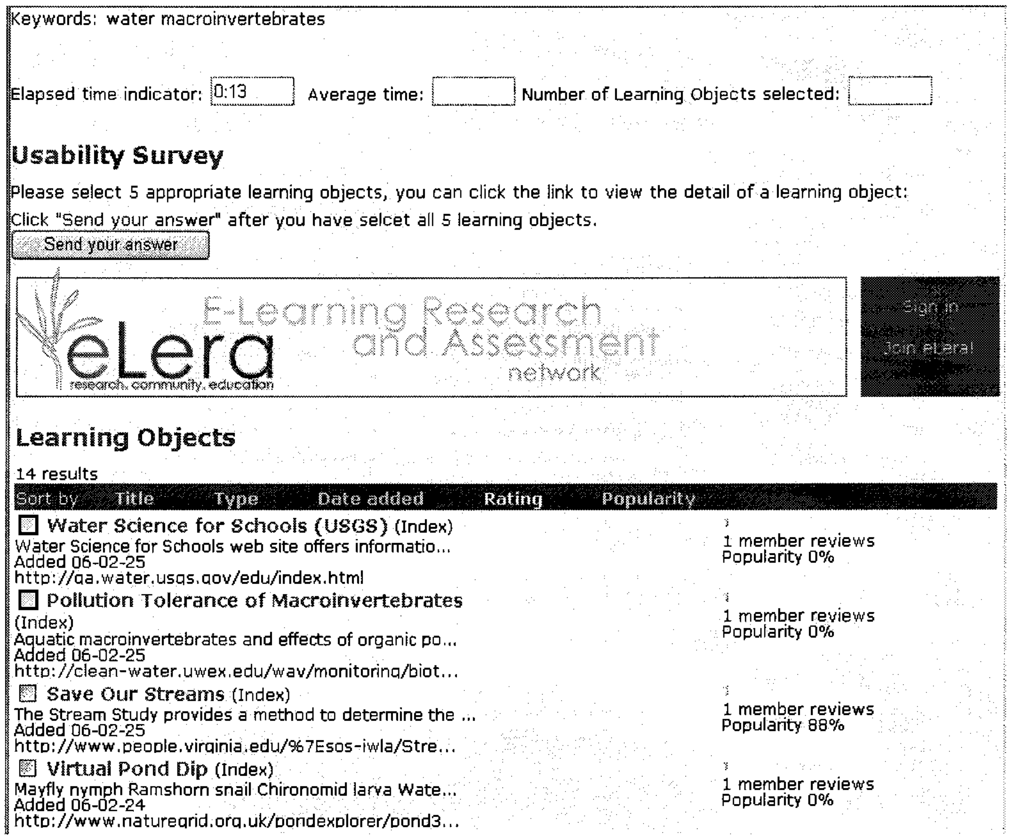
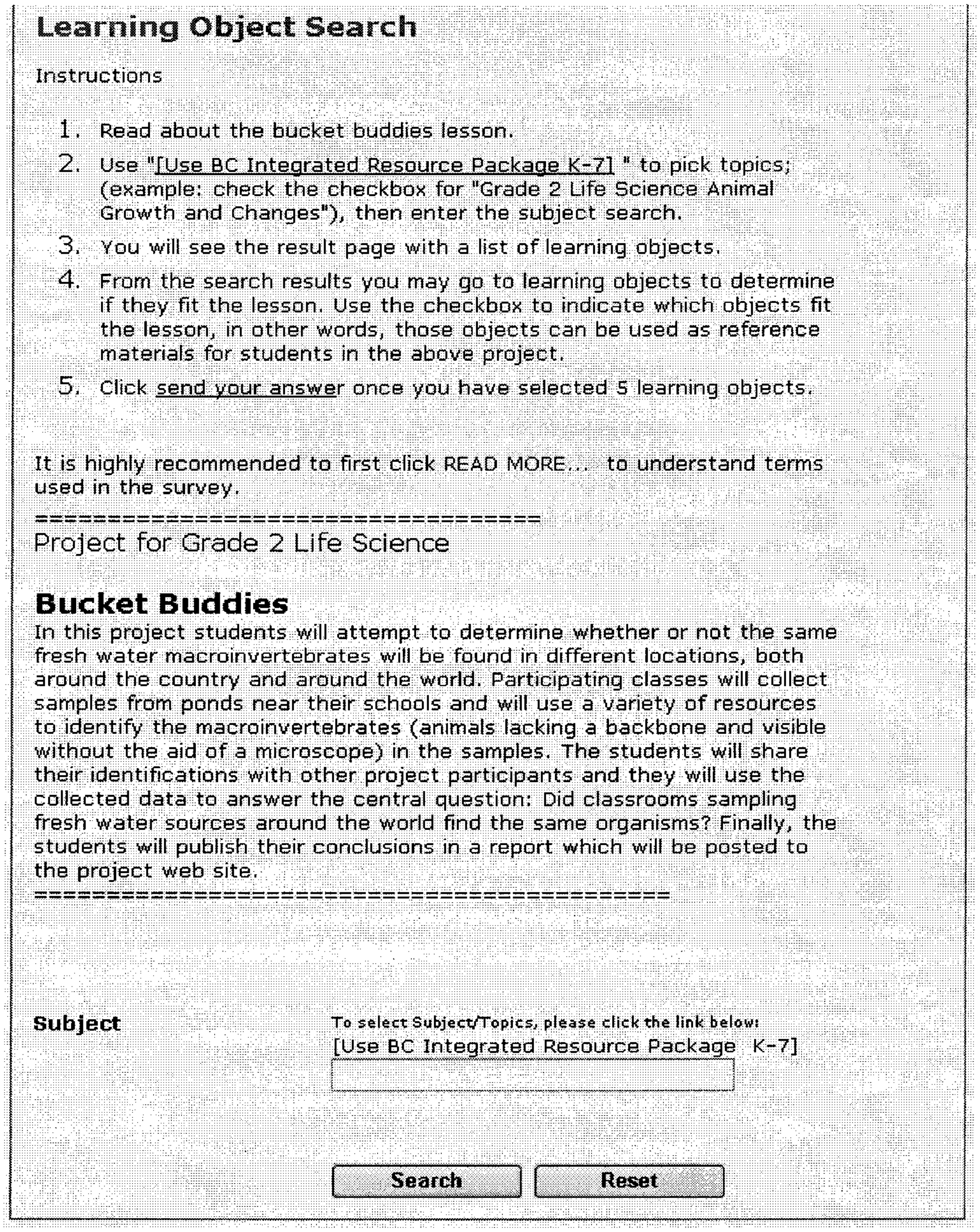


Figure 17: The keyword search result

Subject search procedure

When tasked to perform a subject search, the participant was presented with the subject search instructions shown in Figure 18. As shown in Figure 19, to become familiari with the subject search tool, users were able to click "READ ME" to learn the terms used in the search.



Learning Object Search

Instructions

1. Read about the bucket buddies lesson.
2. Use "[Use BC Integrated Resource Package K-7] " to pick topics; (example: check the checkbox for "Grade 2 Life Science Animal Growth and Changes"), then enter the subject search.
3. You will see the result page with a list of learning objects.
4. From the search results you may go to learning objects to determine if they fit the lesson. Use the checkbox to indicate which objects fit the lesson, in other words, those objects can be used as reference materials for students in the above project.
5. Click send your answer once you have selected 5 learning objects.

It is highly recommended to first click READ MORE... to understand terms used in the survey.

==================================

Project for Grade 2 Life Science

Bucket Buddies

In this project students will attempt to determine whether or not the same fresh water macroinvertebrates will be found in different locations, both around the country and around the world. Participating classes will collect samples from ponds near their schools and will use a variety of resources to identify the macroinvertebrates (animals lacking a backbone and visible without the aid of a microscope) in the samples. The students will share their identifications with other project participants and they will use the collected data to answer the central question: Did classrooms sampling fresh water sources around the world find the same organisms? Finally, the students will publish their conclusions in a report which will be posted to the project web site.

===

Subject To select Subject/Topics, please click the link below:
[Use BC Integrated Resource Package K-7]

Search Reset

Figure 18: Instructions for subject search

When searching for learning resources, teachers, instructional designers and students prefer to use subject terms with which they are already familiar.Our research team has developed mappings between BC IRPs and eLera-DDC subject taxonomy. This mapping allows teachers working with the British Columbia Ministry of Education science curriculum to search, evaluate, and register learning objects catalogued in a repository (eLera) according to a modified form of Dewey Decimal Classification.

What is Integrated Resource Packages (IRPs)?

In Canada each of the ten provinces has separate learning outcomes established for a given subject in the K-12 public education system. In British Columbia (BC), the Ministry of Education has developed learning resources for K-12 known as Integrated Resource Packages (IRPs). The IRPs consist of the provincially required curriculum, suggested ideas for instruction, a list of recommended learning resources (books, videos, electronic resources, etc.), and possible methods for teachers to use in evaluating students' progress.

The following table shows all the topics in BC Integrated Resource Package K-7.

	PROCESSES AND SKILLS OF SCIENCE	LIFE SCIENCE	PHYSICAL SCIENCE	EARTH AND SPACE SCIENCE
Kindergarten	Observing Communicating (sharing)	Characteristics of Living Things	Properties of Objects and Materials	Surroundings
Grade 1	Communicating (recording) Classifying	Needs of Living Things	Force and Motion	Daily and Seasonal Changes
Grade 2	Interpreting Observations Making Inferences	Animal Growth and Changes	Properties of Matter	Air, Water, and Soil
Grade 3	Questioning Measuring and Reporting	Plant Growth and Changes	Materials and Structures	Stars and Planets
Grade 4	Interpreting Data Predicting	Habitats and Communities	Light and Sound	Weather
Grade 5	Designing Experiments Fair Testing	Human Body	Forces and Simple Machines	Renewable and Non-Renewable Resources
Grade 6	Controlling Variables Scientific Problem Solving	Diversity of Life	Electricity	Exploration of Extreme Environments
Grade 7	Hypothesizing Developing Models	Ecosystems	Chemistry	Earth's Crust

See detailed info. at:http://www.bced.gov.bc.ca.proxy.lib.sfu.ca/irp/irp.htm

What is eLera-DDC?

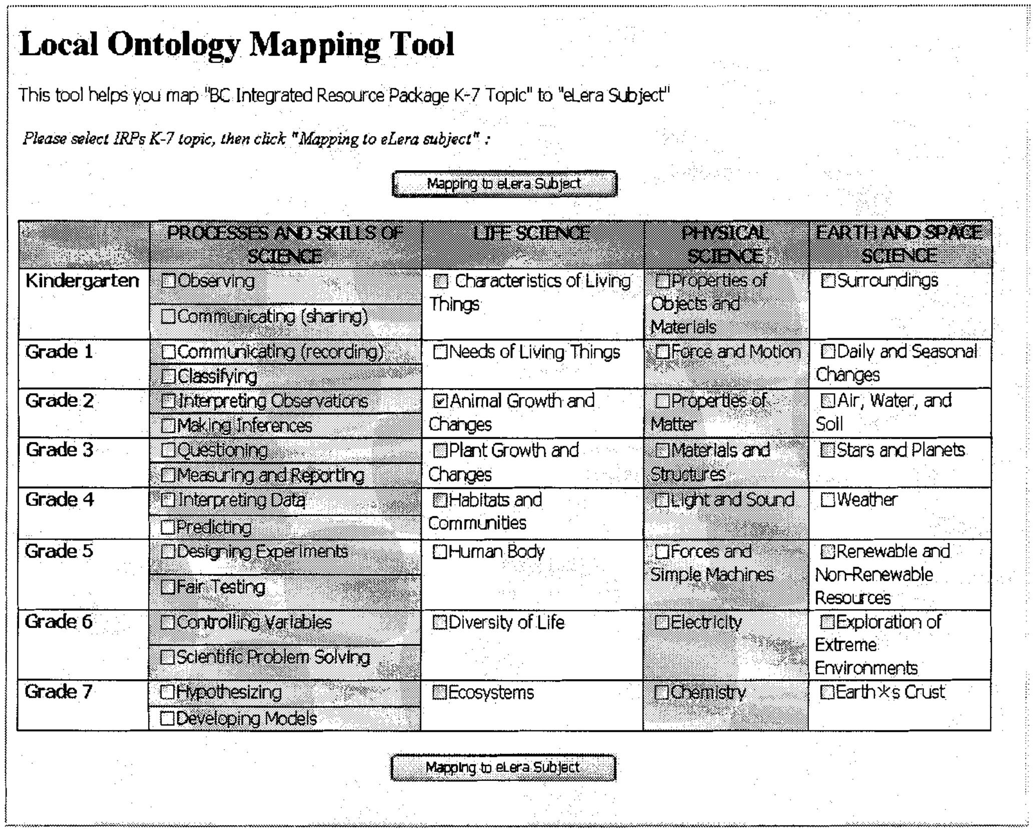
The Dewey Decimal Classification System

The Dewey Decimal Classification (DDC) system was created some 130 years ago. It has been used in library system and the OCLC Online Computer Library Center has held the trademark on the Dewey name(*http://www.oclc.org/dewey/about/worldwide/default.htm*). CanCore recommends DDC as the basic subject taxonomy. eLera is a website (www.elera.net) designed to support a distributed network of teachers, instructors, students, researchers, instructional designers, and media developers. With permission of the Online Computer Library Centre, eLera uses a modified version of the DDC (eLera-DDC) as a subject classification system.

Your contributions will be highly appreciated by our research team

Figure 19: Explanation of terms used in the subject search

In the subject search, after a user chose and submitted topics from the IRP-Topic picker, as shown in Figure 20, the topics were mapped to eLera-DDC subjects by ontology mapping. Subsequently, a result screen similar to that shown in Figure 21 was displayed. The result screen had an identical layout to the result screen for keyword search except for the top line, which shows the subject term used for the search. Finally, the user was instructed to browse and select five learning objects. Similar to the keyword search task, the total time spent was recorded and an average time for each learning object was calculated.



Local Ontology Mapping Tool

This tool helps you map "BC Integrated Resource Package K-7 Topic" to "eLera Subject"

Please select IRPs K-7 topic, then click "Mapping to eLera subject" :

[Mapping to eLera Subject]

	PROCESSES AND SKILLS OF SCIENCE	LIFE SCIENCE	PHYSICAL SCIENCE	EARTH AND SPACE SCIENCE
Kindergarten	☐Observing ☐Communicating (sharing)	☐ Characteristics of Living Things	☐Properties of Objects and Materials	☐Surroundings
Grade 1	☐Communicating (recording) ☐Classifying	☐Needs of Living Things	☐Force and Motion	☐Daily and Seasonal Changes
Grade 2	☐Interpreting Observations ☐Making Inferences	☑Animal Growth and Changes	☐Properties of Matter	☐Air, Water, and Soil
Grade 3	☐Questioning ☐Measuring and Reporting	☐Plant Growth and Changes	☐Materials and Structures	☐Stars and Planets
Grade 4	☐Interpreting Data ☐Predicting	☐Habitats and Communities	☐Light and Sound	☐Weather
Grade 5	☐Designing Experiments ☐Fair Testing	☐Human Body	☐Forces and Simple Machines	☐Renewable and Non-Renewable Resources
Grade 6	☐Controlling Variables ☐Scientific Problem Solving	☐Diversity of Life	☐Electricity	☐Exploration of Extreme Environments
Grade 7	☐Hypothesizing ☐Developing Models	☐Ecosystems	☐Chemistry	☐Earth×s Crust

[Mapping to eLera Subject]

Figure 20: IRP-topic picker

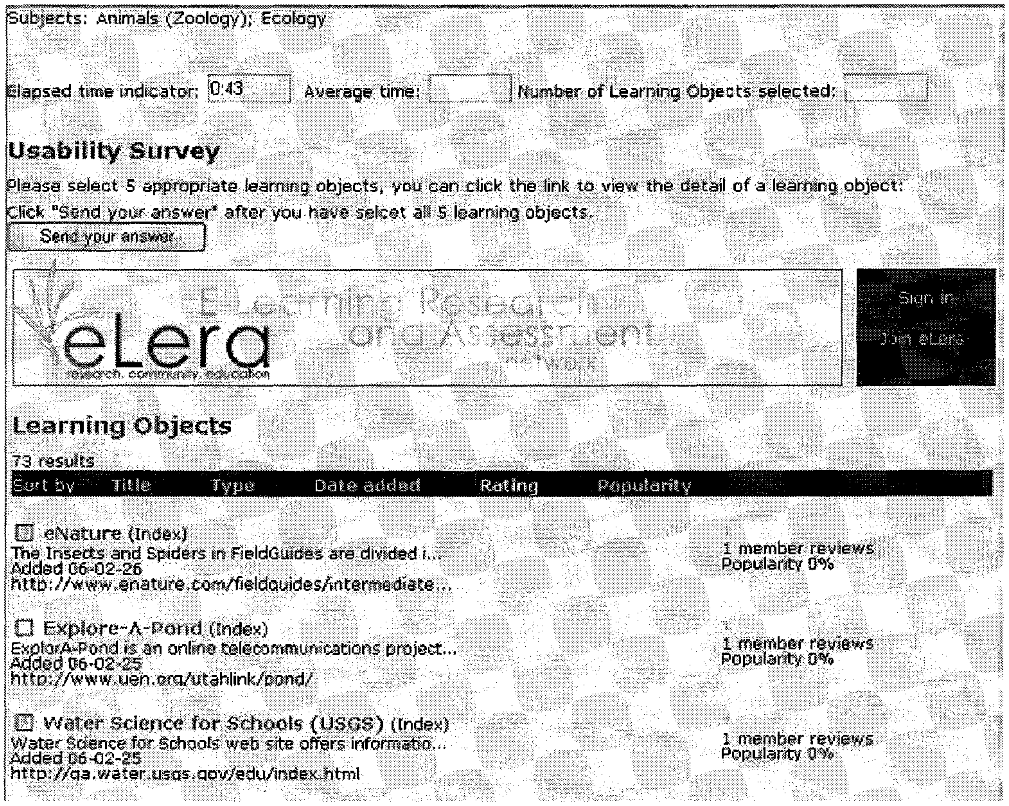


Figure 21: The subject search result display

Results

Table 5 shows a summary of the results including means, medians, standard deviations, skewness, and kurtosis.

Table 5: Descriptive statistics

	Keyword search		Subject search	
	Statistic	Std. Error	Statistic	Std. Error
Effectiveness(a)				
Mean	4.33		5.29	
Median	5.00		5.00	
Std. Deviation	1.15		1.65	
Skewness	-1.82	.50	2.09	.50
Kurtosis	2.65	.97	7.86	.97

Efficiency(b)				
Mean	32.73		28.90	
Median	20.00		15.00	
Std. Deviation	33.51		28.03	
Skewness	1.24	.50	1.20	.50
Kurtosis	.71	.97	.115	.97
Satisfaction(c)	Statistic	Std. Error		
Mean	7.42			
Median	8			
Std. Deviation	1.50			
Skewness	-.60	.52		
Kurtosis	.19	1.01		

Notes. This is a summary of the results by participants. (a). Effectiveness is based on number of learning objects collected by each participant. (b). Efficiency is based on mean duration (seconds) for each participant; (c). Satisfaction is based on a 1-10 scale, 1= prefer keyword search; 5= no particular preference; 10= prefer subject search.

Effectiveness

First, we checked the extent to which participants had completed their tasks. A completed task means a participant was able to select at least five learning objects in a search, as per the instructions. We found that 76.7% of participants completed the keyword search task and 90.5% completed the subject search task (see Appendix F). The kurtosis statistic reported in Table 5 shows that the effectiveness data are not normally distributed. Therefore, a Wilcoxon signed ranks test was used to determine if the dependent measures differed statistically. Table 6 shows that a difference between the number of objects found in the keyword and subject search was statistically detected and subject search was better.

Table 6: Wilcoxon test result for effectiveness (N=21)

Ranks	Negative Ranks	Positive Ranks	Ties	Total	Z	Asymp. Sig. (2-tailed)
Keyword-subject						
Participants	8 (a)	1 (b)	12 (c)	21		
Mean Rank	5.31	2.50				
Sum of Ranks	42.50	2.50				
Statistics						
Keyword-subject					-2.399 (d)	.016

Note. a: keyword < subject; b: keyword > subject; c: keyword = subject; d: Based on positive ranks.

In the same vein, we also found that the total number of distinct learning objects collected by all participants by each method was different. There were 41 distinct learning objects in total that were collected by all participants in keyword search. In comparison, there were a total of 29 distinct learning objects collected by all participants in subject search (see Appendix B & C).

We looked at the quality of the top five learning objects collected in both search methods, and found all of them to be quite relevant to the lesson. In other words, the quality is high, however, if we looked at convergence, we found that the top five learning objects account for 43.6% of the total selected learning objects in keyword search (see Appendix B) and 53.7% for the total selected learning objects by subject search (see Appendix C). Therefore it can be seen that users tend to be more convergent in selecting learning objects by subject search.

Looking at the results by user (see Table 5), subject search with ontology mapping collected 5.29 learning objects on average, while keyword search collected 4.33

learning objects. Therefore, participants were able to collect more learning objects in subject search.

Efficiency

If we disregard the searching methods, the duration average for selecting a learning object is 28.5 seconds (see Appendix A). However, if we look at the duration average by learning object in each search method, we found that the duration average was 30.8 seconds in keywords search (see Appendix D) and 26.6 seconds in subject search (see Appendix E). Therefore, subject search takes less time on average. Looking at duration average by user in each method, it was found to be 32.7 seconds in keyword search and 28.9 seconds in subject search (see Table 5). A Wilcoxon test result showed that there is no significant difference in duration average by user in the two methods (see Table 7). In addition, if we look at the order that each method was performed by each participant, 18 out of 21 times (or 85.7%) the second search method took less time than the first, no matter which search it was. In 11 out of 21 times, the subject search was performed first (see Appendix A). Apparently, there is an advantage for the method performed later, since a user may have already examined the same learning object in the previous search, and did not have to spend any more time to select the learning object.

Table 7: Wilcoxon test result for efficiency (N=21)

Ranks	**Negative Ranks**	**Positive Ranks**	**Ties**	**Total**	**Z**	**Asymp. Sig. (2-tailed)**
Keyword-subject						
N	11(a)	10 (b)	0 (c)	21		
Mean Rank	10.77	11.25				
Sum of Ranks	118.50	112.50				
Statistics						
Keyword-subject					-.104 (d)	.917

Note. a: keyword < subject; b: keyword > subject; c: keyword = subject; d: Based on positive ranks.

Satisfaction

One way to look at the user satisfaction is to see the average score rated by participants on a 10-point scale, where 1 means that a user prefers to use keyword search, 5 means there is no particular preference, and 10 means that a user prefers to use subject search. There were 19 votes, and the average score is 7.42 (see Table 5, Appendix G). Statistically, we are 95% sure that the average score in the population is between 6.70 and 8.14; therefore, subject (with ontology mapping) is preferred.

User satisfaction can also be reflected by participants' free-text comments which were optional for all participants. There were eight participants who made additional comments. In general, those comments indicated that, compared to keyword search, "subject search provides more related search results" and is "more relevant." However, one user commented that subject search is too general to help identify a specific topic (see Table 8).

Table 8: Comments on search methods

User	Comments
1	Looks a bit technical and sometimes confusing. However, this is a classic important research
2	Comparing to "keyword search", "subject search" provides more related search results with high popularity“. "Subject search" likely would rank search results not on data that could be manipulated by learning object title, but by using strength of the learning object topic and category. 'It's greatly helpful for us to locate the learning objects we really want by classifying the topics of them. One more comment is that the search results of "subject search" should be placed in order of popularity. Overall, "subject search" is productive to help learning objects researchers.
3	The "subject search" provides more related searching results.
4	It would be useful if the search system had longer descriptions of learning objects in the initial list of results.
5	Subject search is too general to help identifying a specific topic.
6	Sometimes keywords searching return little data. The result of subject search is more relevant.
7	Subject search will return more results but the accuracy is not that high.
8	The subject search produced more results, and the ordering of search results was better. However, I was able to do the keyword search much more quickly because I recognized some of the good learning resources from the subject search I had done immediately before. I think the sequence of the searches biases the results.

Discussion of Usability Evaluation

This usability evaluation aims to find out to what extent the ontology mapping approach can help teachers and students find learning resources with effectiveness, efficiency, and satisfaction in the context of BC science education. It can be seen that users were able to search learning objects by BC-IRPs through a subject search, while before only keyword search was available for them. The analysis of the results revealed that users' overall experience was improved by subject search with ontology mapping.

First, subject search with ontology mapping enabled user to retrieve learning objects more effectively. Users could finish their tasks with less effort and they had a greater tendency to converge on a set of commonly preferred learning resources.

Second, users in this research retrieved learning resources more efficiently with subject search. The average time for finding a learning object in subject search was less than in keyword search. However, because this difference between the tasks was not statistically significant, these differences cannot be attributed to the properties of subject and keyword search. The efficiency result is important in interpreting the effectiveness result because it demonstrates that the greater effectiveness of subject search cannot be attributed to difference in search time.

Third, it can be seen that users were more satisfied with subject search than with ontology mapping, which enabled them to search learning resources using terms with which they were familiar. This has well-supported previous research in this field (Recker, Dorward, & Nelson, 2004). Teachers generally prefer resources to be categorized by familiar terms, such as grade level, content area, and type.

As mentioned at the beginning of the chapter, usability testing as a research tool, can range from a quantitative approach characterized by large sample sizes, complex test designs, and expensive lab setup, to less formal qualitative studies with only a few participants. In this research, we conducted the usability testing in an online environment, which is simple, with fewer support people needed. It served our purpose in this research though it is not the best technique. The findings were good enough to reflect the issues we were investigating. Since this testing lacked direct communication and observation of the non-verbal responses of the users, we were unable to collect more accurate data for users' search time. As mentioned in the findings, we found that there is no significant difference in duration average by user between subject search and keyword search though we expected a user would spend much less time in subject search. The possible reasons are: (1) The time for selecting keyword is not counted in the system. Users have reported that it was hard to pick a "proper" keyword(s) for keyword search. It usually takes a while to select keywords, however this was not counted in the total searching time. (2) Most of the participants were unfamiliar with BC-IRP topics and there was a learning curve for the first-time user. (3) There was insufficient statistical power to detect a true difference in search time. It could be improved by more careful design. Furthermore, usability testing could be also complicated by many other factors such as the ability of the participants, and limitations of materials used (e.g., limited learning objects in the repository).

The overall findings from the usability evaluation showed a strong support for our efforts in addressing local needs. The subject search with ontology mapping approach can also shed light on ways to address multi-dimensional local needs in sharing learning resources, such as student grade level, pedagogical strategy, and learning outcomes of the course.

CHAPTER 6.
IMPLICATIONS OF FINDINGS FOR EDUCATION AND E-LEARNING RESEARCH

The advances of educational technology, especially the emergence of large repositories of web-based learning resources, have provided more convenient methods of accessing richer educational resources for teachers and learners but have also introduced a new problem: it is time consuming to find the "best-fit" results in the resource overflow. To address this new challenge, many evaluation instruments have been developed to select learning resources by providing reviews. Among them is eLera, a set of web-based tools we have developed for communities of teachers, learners, instructional designers, and developers. Compatible with current metadata standards and designed to assist researchers in gathering data on evaluation processes, eLera provides a learning object review instrument (LORI) and other features supporting collaborative evaluation. eLera provides limited translation of evaluations and subject taxonomies across communities using different languages and terminology, and has been used to teach educators how to assess the quality of multimedia learning resources.

It has been observed that when working with learning objects, teachers, instructional designers, and students prefer to use subject terms with which they are already familiar. I have designed and implemented a mapping ontology supporting translation between local and central domain ontologies. An implemented case shows how the mapping ontology can allow teachers working with the British Columbia

Ministry of Education science curriculum to search, evaluate, and register learning objects catalogued in a repository (eLera) according to a modified form of Dewey Decimal Classification.

With ontology mapping, IRP topics can be used as subject search to retrieve learning objects that match the topics, while before, a user had to use keyword search. In order to compare the quality of search results, subject search, which uses local ontology mapping, is compared with traditional keyword search. The recall-precision data shows that subject search had higher precision level in both cases (single keyword and multiple keywords). The results support the ontology mapping approach in terms of information retrieval by system. This approach has overcome some limitations of keyword search, such as not being able to search synonyms. For example, using ecosystems as a keyword will not retrieve learning objects tagged with bionomics or ecology. In comparison, retrieving learning object with ecology in the subject search will return all the learning objects in the same subject area. Another advantage of ontology mapping is its ability to deal with IRP topics that cover more than one subject area; e.g., Grade 2 Life Science is mapped to DDC subjects animals (zoology) and ecology. Therefore, by mapping, a subject search can retrieve learning objects in related subjects.

In addition, the usability evaluation of ontology mapping has complemented the evaluation from the users' point of view. The results indicate that ontology mapping enables users to search for learning resources using familiar terms with subject search, and subject search offered a better user experience with regard to effectiveness, efficiency, and user satisfaction.

Limitations of This Research

There are some limitations in the methods used for this research. First, the Precision- Recall evaluation method, in which relevance is dependent on subjective judgement, the results don't take into account the degree of relevance. Second, the fit of participants for the usability evaluation is not perfect, since I was unable to recruit teachers, instructional designers, and grade school students. Due to constraints on time and subjects, the participants were students and teachers from Simon Fraser University, who were not as familiar with the BC IRP topics (although they were given detailed instructions online prior to participation). Furthermore, because the usability evaluation was conducted online, it was not controlled as well as if testing was done in a lab. Nevertheless it has been reported that "discount usability testing," using a very small number of test subjects and a simple recorder, can find 80% of the usability problems (Barnum, 2002, pp. 9-12).

Finally, this research does not address the process of creating a mapping ontology. It is theoretically possible to build dynamic tools that make mapping recommendations by machine aggregation of users' inputs. Currently users must rely on domain exporters to come to consensus on each mapping relation. We suspect that dynamic tools for creating mapping ontologies will emerge after the advantages of semantically-mapped searches are demonstrated.

Implications for Education

Within the aforementioned methodological limitations, the mapping scheme has been found to function effectively. The innovation described here is significant because it allows greater standardization of broadly-accepted classification systems, while supporting the adoption of local classification systems that better match the needs of smaller groups. Supported by the "semantic cobblestone" concept, the adaptation of a core ontology such as the Library of Congress classification system as a universal subject taxonomy into which a large number of local subject taxonomies can be mapped via ontology mapping supports the convergence of classifications suggested by the CanCore implementation guide (Friesen et al., 2003). Therefore users in one community will be able to use the metadata generated by users in another community, or even in other languages.

Furthermore, the ontology mapping could also smooth the interoperable federation of local repositories that use different local taxonomies, so that interchange between learning objects by subject is possible among search utilities.

Educators do not simply choose objects by subject matter and grade level. Rather, they are likely to examine the pedagogical model implicit in the object, the time and duration of the object's use, and its alignment with the learning outcomes of the course. Educators are concerned for the intellectual and social development of the learners - often the content of the resource is not the main objective of a lesson, but rather is used to trigger inquiry, reflection, and an exploration of values. Ontology mapping has the potential to address those multi-dimensional needs. The student grade level, pedagogical strategy, local earning outcomes of a course, all could be mapped into a rich taxonomical information indicating the local learning outcomes, the local content descriptions, and the pedagogical design of the object, that would enrich the object descriptions and enable a wide range of future services related to the selection of learning objects for specific instructional contexts.

Future Research in This Field

The next step will be to evaluate this approach through extended laboratory and field testing, and redesign the user interface to make it more user-friendly.

Currently though, users must rely on domain exporters to come to consensus on each mapping relation which is static once it has been done. Inappropriate mappings caused by new developments in the field could lead to a failure of mapping in practice. Therefore, the exploration of dynamic tools for creating mapping ontologies is important for the quality of ontology mapping. Dynamic collaboration of subject matter experts will improve the mapping qualities between the core ontology and local ontologies, and could allow them to evolve with time and new developments in the area.

In addition, the mapping technique presented here has the potential to extend beyond education systems to user-centric information retrieval systems that use folksonomies to supplement existing classification systems. Personal collection of terms could be shared among online users to express similar interests. Mapping can be used to bridge different terms and converge users on some popular terms which then can be seen as “core terms” in grouping resources for users who share interests.

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APPENDICES

Appendix A: Usability Survey Data Summary

DataId	QuestionId	Learning object	User	Duration Average (in seconds)
260	81	Pollution Tolerance of Macroinvertebrates	001	90
261	81	Save Our Streams	001	90
262	81	Virtual Pond Dip	001	90
263	81	Macroinvertebrate Menu	001	90
264	81	Avian communities in Florida habitats	001	90
265	82	Explore-A-Pond	001	88
266	82	Pollution Tolerance of Macroinvertebrates	001	88
267	82	Macroinvertebrate Menu	001	88
268	82	The Electronic Zoo Invertebrates	001	88
269	82	Earth on Edge: Ecosystems	001	88
348	81	Save Our Streams	002	8
349	81	The Living Museum	002	8
350	81	Specific Animals	002	8
351	81	Plant Ecosystems	002	8
352	81	Community and Ecosystems	002	8
353	82	Explore-A-Pond	002	6
354	82	Water Science for Schools (USGS)	002	6
355	82	Save Our Streams	002	6
356	82	Pond Life Game	002	6
357	82	the Microbe Zoo	002	6
358	81	Animal Diversity Web (ADW)	003	11
359	81	Animal diversity web resources for instructors	003	11
360	81	Animal ages : do dogs age faster than people?	003	11
361	81	DiscoverySchool.com: Animal Classification	003	11
362	81	Animals	003	11
363	82	Animal Diversity Web (ADW)	003	6
364	82	Animal diversity web resources for instructors	003	6
365	82	Climate change and agroecosystems: the effect of elevated atmospheric CO2 and temperature on crop growth, development, and yield	003	6

DataId	QuestionId	Learning object	User	Duration Average (in seconds)
368	82	Water Science for Schools (USGS)	004	13
369	82	Pollution Tolerance of Macroinvertebrates	004	13
370	82	Pond Life Game	004	13
371	82	Macroinvertebrate Menu	004	13
372	82	Water: A Never-Ending Story	004	13
373	81	Explore-A-Pond	004	7
374	81	Water Science for Schools (USGS)	004	7
375	81	Save Our Streams	004	7
376	81	Water: A Never-Ending Story	004	7
377	81	Ecosystems	004	7
378	81	Save Our Streams	005	90
379	81	Virtual Pond Dip	005	90
380	81	The Electronic Zoo Invertebrates	005	90
381	82	Save Our Streams	005	15
382	82	Pollution Tolerance of Macroinvertebrates	005	15
383	82	Pond Life Game	005	15
384	82	Virtual Pond Dip	005	15
385	82	Major Stream Invertebrates	005	15
386	82	Invertebrate Printouts	005	15
387	82	Explore-A-Pond	006	15
388	82	Water Science for Schools (USGS)	006	15
389	82	Save Our Streams	006	15
390	82	Pollution Tolerance of Macroinvertebrates	006	15
391	82	Pond Life Game	006	15
392	81	Water Science for Schools (USGS)	006	5
393	81	Pollution Tolerance of Macroinvertebrates	006	5
394	81	Save Our Streams	006	5
395	81	Virtual Pond Dip	006	5
396	81	The Electronic Zoo Invertebrates	006	5
397	82	eNature	007	58
398	82	Explore-A-Pond	007	58
399	82	Water Science for Schools (USGS)	007	58
400	82	Save Our Streams	007	58
401	82	Nonindigenous Aquatic Species	007	58
402	81	Water Science for Schools (USGS)	007	19
403	81	Pollution Tolerance of Macroinvertebrates	007	19
404	81	Save Our Streams	007	19
405	81	Life is Limit	007	19

DataId	QuestionId	Learning object	User	Duration Average (in seconds)
406	81	Environmental Biology - Ecosystems	007	19
408	81	Major Stream Invertebrates	008	62
409	81	Invertebrate Printouts	008	3
410	81	Pond Life Game	008	202
411	81	Virtual Pond Dip	008	202
412	82	Water Science for Schools (USGS)	008	33
413	82	Macroinvertebrate Menu	008	33
414	82	Major Stream Invertebrates	008	33
415	82	Taking Stock of Biodiversity	008	33
416	82	Let's Make a Tubeworm!	008	33
417	82	Explore-A-Pond	009	25
418	82	Virtual Pond Dip	009	25
419	82	Macroinvertebrate Menu	009	25
420	82	Water: A Never-Ending Story	009	25
421	82	Invertebrate Printouts	009	25
422	81	Explore-A-Pond	009	4
423	81	Pond Life Game	009	4
424	81	Virtual Pond Dip	009	4
425	81	Macroinvertebrate Menu	009	4
426	81	Invertebrate Printouts	009	4
427	81	Explore-A-Pond	0010	47
428	81	Pollution Tolerance of Macroinvertebrates	0010	47
429	81	Pond Life Game	0010	47
430	82	Explore-A-Pond	0010	64
431	82	Water Science for Schools (USGS)	0010	64
432	82	Save Our Streams	0010	64
433	82	Pollution Tolerance of Macroinvertebrates	0010	64
434	82	Macroinvertebrate Menu	0010	64
435	82	Pollution Tolerance of Macroinvertebrates	0011	66
436	82	Pond Life Game	0011	66
437	81	Pollution Tolerance of Macroinvertebrates	0011	44
439	82	Explore-A-Pond	0012	91
440	82	Water Science for Schools (USGS)	0012	91
441	82	Save Our Streams	0012	91
442	82	Pond Life Game	0012	91
443	82	Virtual Pond Dip	0012	91
444	81	Explore-A-Pond	0012	21

DataId	QuestionId	Learning object	User	Duration Average (in seconds)
445	81	Pond Life Game	0012	21
446	81	Save Our Streams	0012	21
447	81	Virtual Pond Dip	0012	21
449	81	Water Science for Schools (USGS)	0013	27
450	81	Pollution Tolerance of Macroinvertebrates	0013	27
451	81	Save Our Streams	0013	27
452	81	Virtual Pond Dip	0013	27
453	81	Water: A Never-Ending Story	0013	27
454	82	Save Our Streams	0013	6
455	82	Pollution Tolerance of Macroinvertebrates	0013	6
456	82	Pond Life Game	0013	6
457	82	Virtual Pond Dip	0013	6
458	82	Water: A Never-Ending Story	0013	6
460	81	Water Science for Schools (USGS)	0014	37
461	81	Pollution Tolerance of Macroinvertebrates	0014	37
462	81	Save Our Streams	0014	37
463	81	Priorities for microbial biodiversity research: Summary and recommendations	0014	37
464	82	Explore-A-Pond	0014	12
465	82	Water Science for Schools (USGS)	0014	12
466	82	Save Our Streams	0014	12
467	82	Pollution Tolerance of Macroinvertebrates	0014	12
468	82	Macroinvertebrate Menu	0014	12
469	82	the Microbe Zoo	0014	12
470	82	The Electronic Zoo Invertebrates	0014	12
471	82	Major Stream Invertebrates	0014	12
472	82	Water: A Never-Ending Story	0014	12
473	82	Invertebrate Printouts	0014	12
474	82	Microbial Diversity of Marine and Terrestrial Thermal Springs	0014	12
476	81	Water Science for Schools (USGS)	0015	20
477	81	Pollution Tolerance of Macroinvertebrates	0015	20
478	81	Save Our Streams	0015	20
479	81	Virtual Pond Dip	0015	20
480	81	Environmental Biology - Ecosystems	0015	20
481	82	eNature	0015	46
482	82	Pollution Tolerance of Macroinvertebrates	0015	46

DataId	QuestionId	Learning object	User	Duration Average (in seconds)
483	82	Pond Life Game	0015	46
484	82	Virtual Pond Dip	0015	46
501	82	Explore-A-Pond	0016	11
502	82	Save Our Streams	0016	11
503	82	Pollution Tolerance of Macroinvertebrates	0016	11
504	82	Field Museum	0016	11
505	82	Element Hangman	0016	11
506	82	Pythagoras' Theorem	0016	11
507	82	How Big Is the Universe?	0016	11
508	82	Candy Chemosynthesis: Biochemistry of Hydrothermal Vents	0016	11
509	81	Water: A Never-Ending Story	0016	4
510	81	Earth at night	0016	4
511	81	Antarctic Microbes Colonize under Mars-like Conditions	0016	4
512	81	Candy Chemosynthesis: Biochemistry of Hydrothermal Vents	0016	4
513	81	Life in Extreme Environments (LExEn) Workshop Report	0016	4
514	82	Population Growth and Balance	0017	11
515	82	Newton's First Law	0017	11
516	82	Pythagoras' Theorem	0017	11
517	82	Pythagorean Triples	0017	11
518	82	Moving Targets	0017	11
519	81	Learning Objects Portal	0017	4
520	81	BBC Fossil Fun - Skeleton Jigsaw	0017	4
521	81	Zen Garden	0017	4
522	81	6 Billion Human Beings	0017	4
523	81	Clinical Pharmacology	0017	4
524	81	Water Science for Schools (USGS)	0018	10
525	81	Save Our Streams	0018	10
526	81	Water: A Never-Ending Story	0018	10
527	81	Environmental Biology - Ecosystems	0018	10
528	81	AUSTRALIAN ECOSYSTEMS	0018	10
529	82	BBC Fossil Fun - Skeleton Jigsaw	0018	6
530	82	Save Our Streams	0018	6
531	82	Element Hangman	0018	6
532	82	Major Stream Invertebrates	0018	6
533	82	Water: A Never-Ending Story	0018	6

DataId	QuestionId	Learning object	User	Duration Average (in seconds)
535	82	eNature	0019	7
536	82	Explore-A-Pond	0019	7
537	82	Water Science for Schools (USGS)	0019	7
538	82	Pollution Tolerance of roinvertebrates	0019	7
539	82	Water: A Never-Ending Story	0019	7
540	81	Pollution Tolerance of Macroinvertebrates	0019	3
541	81	Save Our Streams	0019	3
543	82	Explore-A-Pond	0020	15
544	82	Water Science for Schools (USGS)	0020	15
545	82	Save Our Streams	0020	15
546	82	Pollution Tolerance of Macroinvertebrates	0020	15
547	82	Pond Life Game	0020	15
548	81	The Electronic Zoo Invertebrates	0020	54
549	81	Water: A Never-Ending Story	0020	54
550	81	Environmental Biology - Ecosystems	0020	54
551	81	The winds of (evolutionary) change: Breathing new life into microbiology	0020	54
552	81	Priorities for microbial biodiversity research: Summary and recommendations	0020	54
553	82	Explore-A-Pond	0021	13
554	82	Water Science for Schools (USGS)	0021	13
555	82	Save Our Streams	0021	13
556	82	Pollution Tolerance of Macroinvertebrates	0021	13
557	82	Pond Life Game	0021	13
558	81	The Wonderful World of Insects	0021	65
559	81	Animal Diversity Web (ADW)	0021	65
560	81	Animal diversity web resources for instructors	0021	65
561	81	DiscoverySchool.com: Animal Classification	0021	65
562	81	The Shape of Life	0021	65
			Duration Average	28.3

Note. QuestionId 81 indicates the keyword search, and QuestionId 82 indicates the subject search.

Appendix B: Statistics for Keyword Search Result

Selected Learning Objects	Frequency	Percentage
Save Our Streams	12	12.8%
Pollution Tolerance of Macroinvertebrates	9	9.6%
Virtual Pond Dip	8	8.5%
Water Science for Schools (USGS)	7	7.5%
Water: A Never-Ending Story	5	5.3%
Environmental Biology - Ecosystems	4	4.3%
Pond Life Game	4	4.3%
Explore-A-Pond	4	4.3%
The Electronic Zoo Invertebrates	3	3.2%
DiscoverySchool.com: Animal Classification	2	2.1%
Animal diversity web resources for instructors	2	2.1%
Animal Diversity Web (ADW)	2	2.1%
Macroinvertebrate Menu	2	2.1%
Priorities for microbial biodiversity research: Summary and recommendations	2	2.1%
Invertebrate Printouts	2	2.1%
The Shape of Life	1	1.1%
DiscoverySchool.com: Animal Classification	1	1.1%
Animal diversity web resources for instructors	1	1.1%
Animal Diversity Web (ADW)	1	1.1%
The Wonderful World of Insects	1	1.1%
The Living Museum	1	1.1%
Specific Animals	1	1.1%
Plant Ecosystems	1	1.1%
Community and Ecosystems	1	1.1%
Climate change and agroecosystems: the effect of e...	1	1.1%
Avian communities in Florida habitats	1	1.1%

Selected Learning Objects	Frequency	Percentage
Animal ages : do dogs age faster than people?	1	1.1%
AUSTRALIAN ECOSYSTEMS	1	1.1%
Clinical Pharmacology	1	1.1%
6 Billion Human Beings	1	1.1%
Zen Garden	1	1.1%
BBC Fossil Fun - Skeleton Jigsaw	1	1.1%
Learning Objects Portal	1	1.1%
Life in Extreme Environments (LExEn) Workshop Report	1	1.1%
Candy Chemosynthesis: Biochemistry of Hydrothermal Vents	1	1.1%
Antarctic Microbes Colonize under Mars-like Conditions	1	1.1%
Earth at night	1	1.1%
Ecosystems	1	1.1%
Life is Limit	1	1.1%
Major Stream Invertebrates	1	1.1%
The winds of (evolutionary) change: Breathing new life into microbiology	1	1.1%
Total number of Learning Objects collected	41	
Top 5 Learning Objects		43.6%

Appendix C: Statistics for Subject Search Result

Selected Learning Objects	Frequency	Percentage
Pollution Tolerance of Macroinvertebrates	13	12.0%
Save Our Streams	12	11.1%
Explore-A-Pond	12	11.1%
Water Science for Schools (USGS)	11	10.2%
Pond Life Game	10	9.3%
Macroinvertebrate Menu	7	6.5%
Water: A Never-Ending Story	6	5.6%
Virtual Pond Dip	5	4.6%
Major Stream Invertebrates	4	3.7%
Invertebrate Printouts	3	2.8%
eNature	3	2.8%
Pythagoras' Theorem	2	1.9%
Element Hangman	2	1.9%
The Electronic Zoo Invertebrates	2	1.9%
the Microbe Zoo	2	1.9%
Earth on Edge: Ecosystems	1	0.9%
The Living Museum	1	0.9%
BBC Fossil Fun - Skeleton Jigsaw	1	0.9%
Moving Targets	1	0.9%
Pythagorean Triples	1	0.9%
Newton's First Law	1	0.9%
Population Growth and Balance	1	0.9%
Candy Chemosynthesis: Biochemistry of Hydrothermal Vents	1	0.9%
How Big Is the Universe?	1	0.9%
Field Museum	1	0.9%
Microbial Diversity of Marine and Terrestrial Thermal Springs	1	0.9%

Selected Learning Objects	Frequency	Percentage
Nonindigenous Aquatic Species	1	0.9%
Taking Stock of Biodiversity	1	0.9%
Let's Make a Tubeworm!	1	0.9%
Total number of Learning Objects collected	**29**	
Top 5		**53.7%**

Appendix D: Keyword Search Summary by Learning Object

Learning object	User	Duration (seconds)
Pollution Tolerance of Macroinvertebrates	001	90
Save Our Streams	001	90
Virtual Pond Dip	001	90
Macroinvertebrate Menu	001	90
Avian communities in Florida habitats	001	90
Save Our Streams	002	8
The Living Museum	002	8
Specific Animals	002	8
Plant Ecosystems	002	8
Community and Ecosystems	002	8
Animal Diversity Web (ADW)	003	11
Animal diversity web resources for instructors	003	11
Animal ages : do dogs age faster than people?	003	11
DiscoverySchool.com: Animal Classification	003	11
Animals	003	11
Explore-A-Pond	004	7
Water Science for Schools (USGS)	004	7
Save Our Streams	004	7
Water: A Never-Ending Story	004	7
Ecosystems	004	7
Save Our Streams	005	90
Virtual Pond Dip	005	90
The Electronic Zoo Invertebrates	005	90
Water Science for Schools (USGS)	006	5
Pollution Tolerance of Macroinvertebrates	006	5
Save Our Streams	006	5
Virtual Pond Dip	006	5
The Electronic Zoo Invertebrates	006	5
Water Science for Schools (USGS)	007	19
Pollution Tolerance of Macroinvertebrates	007	19
Save Our Streams	007	19
Life is Limit	007	19
Environmental Biology - Ecosystems	007	19
Major Stream Invertebrates	008	62
Invertebrate Printouts	008	3
Pond Life Game	008	202

Learning object	User	Duration (seconds)
Virtual Pond Dip	008	202
Explore-A-Pond	009	4
Pond Life Game	009	4
Virtual Pond Dip	009	4
Macroinvertebrate Menu	009	4
Invertebrate Printouts	009	4
Explore-A-Pond	0010	47
Pollution Tolerance of Macroinvertebrates	0010	47
Pond Life Game	0010	47
Pollution Tolerance of Macroinvertebrates	0011	44
Explore-A-Pond	0012	21
Pond Life Game	0012	21
Save Our Streams	0012	21
Virtual Pond Dip	0012	21
Water Science for Schools (USGS)	0013	27
Pollution Tolerance of Macroinvertebrates	0013	27
Save Our Streams	0013	27
Virtual Pond Dip	0013	27
Water: A Never-Ending Story	0013	27
Water Science for Schools (USGS)	0014	37
Pollution Tolerance of Macroinvertebrates	0014	37
Save Our Streams	0014	37
Priorities for microbial biodiversity research: Summary and recommendations	0014	37
Water Science for Schools (USGS)	0015	20
Pollution Tolerance of Macroinvertebrates	0015	20
Save Our Streams	0015	20
Virtual Pond Dip	0015	20
Environmental Biology - Ecosystems	0015	20
Water: A Never-Ending Story	0016	4
Earth at night	0016	4
Antarctic Microbes Colonize under Mars-like Conditions	0016	4
Candy Chemosynthesis: Biochemistry of Hydrothermal Vents	0016	4
Life in Extreme Environments (LExEn) Workshop Report	0016	4
Learning Objects Portal	0017	4
BBC Fossil Fun - Skeleton Jigsaw	0017	4
Zen Garden	0017	4
6 Billion Human Beings	0017	4

Learning object	User	Duration (seconds)
Clinical Pharmacology	0017	4
Water Science for Schools (USGS)	0018	10
Save Our Streams	0018	10
Water: A Never-Ending Story	0018	10
Environmental Biology - Ecosystems	0018	10
AUSTRALIAN ECOSYSTEMS	0018	10
Pollution Tolerance of Macroinvertebrates	0019	3
Save Our Streams	0019	3
The Electronic Zoo Invertebrates	0020	54
Water: A Never-Ending Story	0020	54
Environmental Biology - Ecosystems	0020	54
The winds of (evolutionary) change: Breathing new life into microbiology	0020	54
Priorities for microbial biodiversity research: Summary and recommendations	0020	54
The Wonderful World of Insects	0021	65
Animal Diversity Web (ADW)	0021	65
Animal diversity web resources for instructors	0021	65
DiscoverySchool.com: Animal Classification	0021	65
The Shape of Life	0021	65
Duration average		30.8

Appendix E: Subject Search Summary by Learning Object

Learning object	User	Duration (seconds)
Explore-A-Pond	001	88
Pollution Tolerance of Macroinvertebrates	001	88
Macroinvertebrate Menu	001	88
The Electronic Zoo Invertebrates	001	88
Earth on Edge: Ecosystems	001	88
Explore-A-Pond	002	6
Water Science for Schools (USGS)	002	6
Save Our Streams	002	6
Pond Life Game	002	6
the Microbe Zoo	002	6
Animal Diversity Web (ADW)	003	6
Animal diversity web resources for instructors	003	6
Climate change and agroecosystems: the effect of elevated atmospheric CO2 and temperature on crop growth, development, and yield	003	6
DiscoverySchool.com: Animal Classification	003	6
Water Science for Schools (USGS)	004	13
Pollution Tolerance of Macroinvertebrates	004	13
Pond Life Game	004	13
Macroinvertebrate Menu	004	13
Water: A Never-Ending Story	004	13
Save Our Streams	005	15
Pollution Tolerance of Macroinvertebrates	005	15
Pond Life Game	005	15
Virtual Pond Dip	005	15
Major Stream Invertebrates	005	15
Invertebrate Printouts	005	15
Explore-A-Pond	006	15
Water Science for Schools (USGS)	006	15
Save Our Streams	006	15
Pollution Tolerance of Macroinvertebrates	006	15
Pond Life Game	006	15
eNature	007	58
Explore-A-Pond	007	58
Water Science for Schools (USGS)	007	58
Save Our Streams	007	58
Nonindigenous Aquatic Species	007	58

Learning object	**User**	**Duration (seconds)**
Water Science for Schools (USGS)	008	33
Macroinvertebrate Menu	008	33
Major Stream Invertebrates	008	33
Taking Stock of Biodiversity	008	33
Let's Make a Tubeworm!	008	33
Explore-A-Pond	009	25
Virtual Pond Dip	009	25
Macroinvertebrate Menu	009	25
Water: A Never-Ending Story	009	25
Invertebrate Printouts	009	25
Explore-A-Pond	0010	64
Water Science for Schools (USGS)	0010	64
Save Our Streams	0010	64
Pollution Tolerance of Macroinvertebrates	0010	64
Macroinvertebrate Menu	0010	64
Pollution Tolerance of Macroinvertebrates	0011	66
Pond Life Game	0011	66
Explore-A-Pond	0012	91
Water Science for Schools (USGS)	0012	91
Save Our Streams	0012	91
Pond Life Game	0012	91
Virtual Pond Dip	0012	91
Save Our Streams	0013	6
Pollution Tolerance of Macroinvertebrates	0013	6
Pond Life Game	0013	6
Virtual Pond Dip	0013	6
Water: A Never-Ending Story	0013	6
Explore-A-Pond	0014	12
Water Science for Schools (USGS)	0014	12
Save Our Streams	0014	12
Pollution Tolerance of Macroinvertebrates	0014	12
Macroinvertebrate Menu	0014	12
the Microbe Zoo	0014	12
The Electronic Zoo Invertebrates	0014	12
Major Stream Invertebrates	0014	12
Water: A Never-Ending Story	0014	12
Invertebrate Printouts	0014	12
Microbial Diversity of Marine and Terrestrial Thermal Springs	0014	12
eNature	0015	46
Pollution Tolerance of	0015	46

Learning object	**User**	**Duration (seconds)**
Macroinvertebrates		
Pond Life Game	0015	46
Virtual Pond Dip	0015	46
Macroinvertebrate Menu	0015	46
Explore-A-Pond	0016	11
Save Our Streams	0016	11
Pollution Tolerance of Macroinvertebrates	0016	11
Field Museum	0016	11
Element Hangman	0016	11
Pythagoras' Theorem	0016	11
How Big Is the Universe?	0016	11
Candy Chemosynthesis: Biochemistry of Hydrothermal Vents	0016	11
Population Growth and Balance	0017	11
Newton's First Law	0017	11
Pythagoras' Theorem	0017	11
Pythagorean Triples	0017	11
Moving Targets	0017	11
BBC Fossil Fun - Skeleton Jigsaw	0018	6
Save Our Streams	0018	6
Element Hangman	0018	6
Major Stream Invertebrates	0018	6
Water: A Never-Ending Story	0018	6
eNature	0019	7
Explore-A-Pond	0019	7
Water Science for Schools (USGS)	0019	7
Pollution Tolerance of Macroinvertebrates	0019	7
Water: A Never-Ending Story	0019	7
Explore-A-Pond	0020	15
Water Science for Schools (USGS)	0020	15
Save Our Streams	0020	15
Pollution Tolerance of Macroinvertebrates	0020	15
Pond Life Game	0020	15
Explore-A-Pond	0021	13
Water Science for Schools (USGS)	0021	13
Save Our Streams	0021	13
Pollution Tolerance of Macroinvertebrates	0021	13
Pond Life Game	0021	13
Duration average		26.6

Appendix F: Summary by Users

	No. of learning objects collected			Average duration by user (seconds)		
Participants	**Subject Search**	**Keyword Search**	**Difference**	**Subject Search**	**Keyword Search**	**Difference**
1	5	5	0	88	90	-2
2	5	5	0	6	8	-2
3	4	5	-1	6	11	-5
4	5	5	0	13	7	6
5	6	3	3	15	90	-75
6	5	5	0	15	5	10
7	5	5	0	58	19	39
8	5	4	1	33	117.25	-84.25
9	5	5	0	25	4	21
10	5	3	2	64	47	17
11	2	1	1	66	44	22
12	5	4	1	91	21	70
13	5	5	0	6	27	-21
14	11	4	7	12	37	-25
15	5	5	0	46	20	26
16	8	5	3	11	4	7
17	5	5	0	11	4	7
18	5	5	0	6	10	-4
19	5	2	3	7	3	4
20	5	5	0	15	54	-39
21	5	5	0	13	65	-52
Average	5.29	4.33		28.9	32.7	
Completed task (%)	90.5%	76.7%				

Appendix G: User Votes Summary for Preference

User	Score
1	7
2	8
3	9
4	4
5	5
6	8
7	7
8	6
9	8
10	7
11	8
12	8
13	9
14	6
15	6
16	9
17	8
18	8
19	10
Average	7.42

Note. Preference was based on a 1-10 scale, 1= prefer keyword (s) search; 5= no particular preference; 10= prefer subject search.