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Ontology technology to assist learners' navigation in the concept map learning system

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ABSTRACT

Evidence indicates that concept mapping can reduce students' cognitive load and facilitate meaningful learning. Using a concept map description approach, the ontology defines the relationship between concepts that is feasible for resource sharing and reusing. In this study, we implement a concept map learning system with ontology technology to help users search the concept map, determine relationships between nodes or predicates, and find the common concept or predicate among the concepts to help reduce the user's cognitive load.

1. Introduction

ICT progress has resulted in a movement from the traditional teacher-centered approach to a learner-centered approach. When learners are dominant, the course not only uses the same learning materials for all students, but it also uses different materials for different students. Thus, how to implement the learning system for adaptive learning becomes a major issue. The system should guide learners to improve their cognitive structure, while helping their instructor evaluate their knowledge structure.

In the traditional learning assessment, teachers use matching, multiple-choice, true–false, essay, and fill-in-the-blank objective questions to evaluate learners' performance. However, these questions depend on learners' recalling clues or cognitive process, and learners are limited by the items' situation (McClure, Sonak, & Suen, 1999). For example, external factors, the tester's emotion or mistakes, and even ambiguous questions prevent the reflection of the learner's actual performance. With other traditional assessments (e.g., review, report, and explain), the quality of the responses depends on the learner's writing skills or organizational abilities. In addition, teachers' or experts' criteria are sometimes inconsistent. In contrast, concept maps and the navigation learning system are objective means of evaluating the learner's cognitive and knowledge structure.

Novak and Gowin (1984) define concept maps as "graphical representations of knowledge that are comprised of concepts and the relationships between them."

As they draw concept maps, students reflect and construct their knowledge structure after learning: the concept map provides a visual representation of the student's knowledge of a specific topic. Francisco, Nakhleh, Nurrenbern, and Miller (2002) stated that concept maps were designed "to represent how students linked hierarchical material together," and are important for students mining new knowledge from original knowledge. Concept mapping can also be used as a misconception-correction tool that binds concepts with linking keywords to help students see connections among them and organize those connections. The ontology defines the relationship between concepts that facilitates resource-sharing and reusing. Furthermore, the ontology inference function provides adaptive learning content for learners. Chi (2009) states that ontology technologies enable the representation of conceptual relationships among learning materials; thus, ontology can serve as a structured knowledge scheme that assists in the construction of a personalized learning path.

In this study, we implemented an ontology-based concept learning system to help learners search, compare, and integrate concepts that construct their knowledge architecture.

2. Concept map

A concept map is a visual representation of different concepts and their relationships. Novak and Gowin (1984) developed this learning method based on Ausubel's learning theory. It was first used to improve learning in science. Concept maps are tools for organizing a learner's cognitive structure to encourage a deep level of integrated knowledge. Students who use them acquire meaningful, interconnected learning; as a bonus, they "learn how to learn" more effectively. Concept mapping helps students make sense of what they are trying to learn (Cardellini, 2004). With the use of concept mapping, the learning arena can be virtualized in a learner's mind (Shambaugh, 1995). Concept maps are also used to assess a learner's knowledge: a student's concept map can help a teacher assess what the student has learned.

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Concept mapping involves concept nodes and relational links. Concept nodes are connected using certain relational links and logical relations (Sowa, 1984). The proposition connects two nodes; the concept location and link direction determine the framework. A concept has a hierarchical organization, with the general concept at the top and the specific, concrete concepts below. Fig. 1 depicts a concept map of these components.

In resource-based learning scenarios, students are often overwhelmed by the complexity of the knowledge and information. External interactive representation of individual knowledge in graphic format may help them to cope with complex problems (Tergan, Gräber, & Neumann, 2006). Furthermore, concept mapping may reduce learners' cognitive load and extend their simple memory function (Sweller, 1988, 1994). Evidence indicates that concept mapping is a useful strategy to support and foster learners' cognitive comprehension in different teaching and learning scenarios (Jonassen, 1987; O'Donnell, Dansereau, & Hall, 2002).

3. Ontology

Berners-Lee, Hendler, and Lassila (2001) described the Semantic Web as a structure of the meaningful content of Web pages, creating an environment where users can easily roam from page to page. Web pages use tags, semantic messages for agent searching, and these tags must be machine-readable for processing. Ontology offers useful information that makes the Semantic Web feasible.

The term "ontology" has many different definitions. In the context of computer sciences, an ontology defines a set of representational primitives with which to model a domain of knowledge or discourse. In the context of knowledge sharing, an ontology is a specification of a conceptualization. In the knowledge of a domain, the ontology of a program can be described by defining a set of objects and the describable relationships among them that are reflected in the vocabulary that represents knowledge. In such an ontology, definitions associate the names of entities in the universe of discourse (e.g., classes, relations, functions, or other objects) with human-readable text describing what the names mean, and formal axioms that constrain the interpretation and well-formed use of these terms (Gruber, 1993).

Noy & McGuinness (2001) offer the following reasons for developing an ontology:

- To share common understanding of the structure of information among people or software agents.
- To enable reuse of domain knowledge.
- To make domain assumptions explicit.
- To separate domain knowledge from the operational knowledge.
- To analyze domain knowledge.

Knowledge representation and reasoning ontology create a conceptualization symbol system in a domain of discourse; this conceptualization includes objects, concepts, and other entities. The Semantic Web, concept images, RDF, project map, and concept map are knowledge representation forms for simple presentation and thus could be developed by ontology (Soares & Sousa, 2008).

Ontology technology is a concept map authoring tool (e.g., for searching and tracking a learner's learning path). It is able to represent and store concept map information.

The Concept Mapped Project-Based Activity Scaffolding System (CoMPASS) consists of a hypertext system and curriculum modules based on the pedagogical framework of Learning by Design, which has students learn science in the context of design-and-build challenges. The CoMPASS system includes two tightly integrated representations of content, one textual and the other visual (in the form of concept maps). Each CoMPASS screen (Fig. 2) represents a concept such as mass or gravity and provides both a concept map (left half of the screen) and a textual description (right half of the screen) (Kolodner et al., 2003). Puntambekar, Stylianou, and Hubscher (2003) found that students in the maps class visited more goal-related concepts and spent more time on them, improved more on an essay question, and performed better when tested on their depth of knowledge.

The intended use of concept mapping is to provide an opportunity for the teacher to learn what students' current ideas are about the subject of inquiry and to see how students make connections among those ideas. Concept mapping allows students to visualize for themselves their knowledge and their growing understanding. The process of building a concept map can be a valuable learning experience, helping students focus on the relationships among the concepts in the domain knowledge.

The ontology-based concept map learning system (CLS) and CoMPASS use the same practices for student learning, such as the visual navigation through concept mapping, the abstract of knowledge, dynamic learning content, and macroscopic and microscopic issues. Both provide learning paths and strategies to prevent learning loss. Although both use similar concept mapping strategies to facilitate students' learning, these systems differ in many ways (Table 1).

In summary, the CoMPASS uses a database to define courses for learning, whereas the CLS uses ontology. A learner's navigation pattern is influenced by the system architecture that provides the content for the learner. The CLS presents homogeneous content, thus decreasing non-relative content disturbance and increasing homogeneous learning transfer. The CLS merges different knowledge to become new knowledge by the predefined ontol-

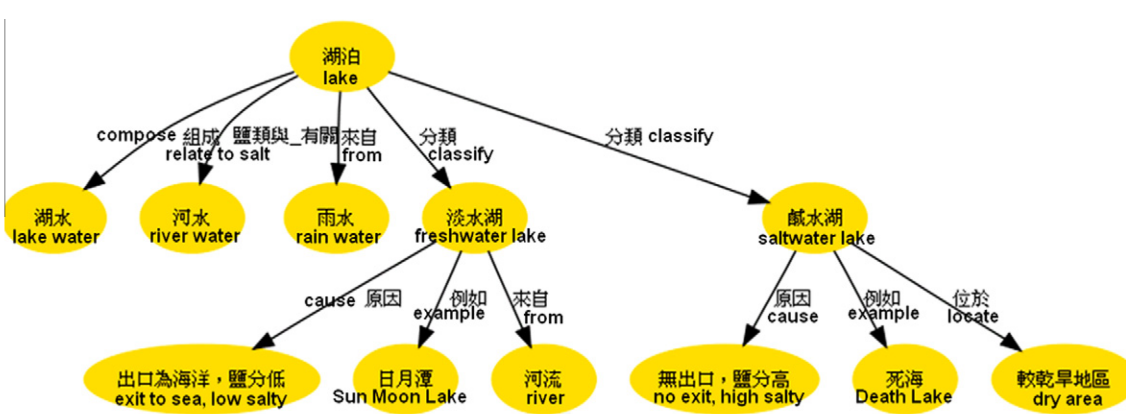

Fig. 1. Concept map components.

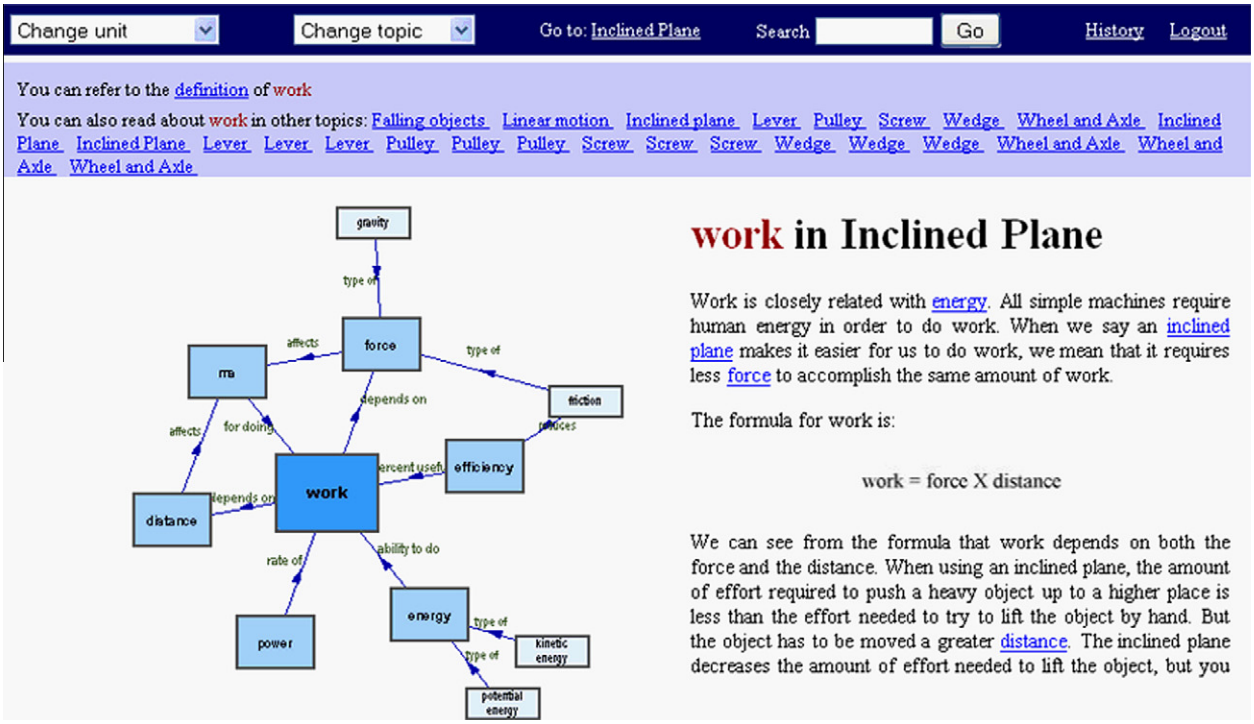

Fig. 2. Snapshot of CoMPASS.

Table 1
Comparison of CoMPASS and CLS.

	CoMPASS	CLS
Course definition	Database	Ontology
Navigation pattern	Heterogeneous	Homogeneous
System aid	Passive	Active
Knowledge representation	Paragraph text	Cognitive structure
Concept transfer path	None	Built-in
Tracking learning log	None	Built-in
Material authoring tool	None	Built-in

ogy. Although the CoMPASS presents the relevant concepts, learners still must organize a new concept; therefore, underachieving students may become frustrated. Furthermore, the CoMPASS provides full-text learning content that may be too challenging for students who have low-level reading ability. In contrast, the CLS follows the knowledge representation theory, and the relationships among concept nodes are illustrated for learners. In addition, the CLS provides visual concept transfer paths that help the learner understand the relationship between concepts, and it provides a learner's log to track learning progress. To assist teachers in creating ontology-based learning material, the CLS provides an authoring tool to import RDF data.

In this study, we adopt experts' views to create course ontology; learners establish concepts among different levels during the course; and the CLS records their learning log to determine appropriate leaning paths for learners. The CLS guides learners in constructing their knowledge structure step by step, avoiding disappointment during the learning process.

4. System implementation

4.1. Framework

- Web Server: Apache
- Programming Language: PHP
- Database: MySQL
- Library: RAP (RDF API for PHP V0.9.6)
- RDF Query language: RDQL
- Graph Visualization Software: Graphviz

The results of two RDF parser tests by W3C (2003) indicate that the RAP V0.7 passed 96% positive test, and the RAP model is similar to the Jena model, although the OWL reasoning functionality is less than that of the Jena (RAP, 2008). For PHP and MySQL developers, the RPA is an ideal tool to implement an ontology-based platform in RDF. We created the CLS with the RAP library to complete the search, browse, share, and organize course modules on the Web. When the users submit their requests via the browser, the system converts to RDQL syntax and accesses data via the RAP; then the RAP loads the results from the database or RDF files to the memory (see Fig. 3). If the RAP core module meets the user's request, it is passed to the relative modules to convert to a visual diagram for users (Fig. 4).

An RDQL query can have a set of constraints on the values of the query variables. Filter expressions supported by RAP are arithmetic conditions (including multiplicative and additive operators), string equality expressions, and Perl-style regular expressions. Multiple constraints can be combined using logical operators. A list of variables required in the answer set is specified in the SELECT clause of an RDQL query. To make the query easier for humans to read and write, RDQL provides a way to shorten the length of URIs by defining a string prefix:

```
SELECT ?person
WHERE (?person, <info:age>, ?age)
AND ?age >= 26
USING info FOR <http://example.org/people#>
```

4.2. Modules

Fig. 5 depicts the CLS module layout, and the functions are as follows:

Positive Parser Test (128 Approved)

Test	rdflib: RDF Library for Python	RDF API for PHP V0.7	RDFStore RDF/XML Parser	Raptor RDF Parser	3store RDF engine	Jena2	Euler
Percent Passing (of 128 tests)	98%	96%	79%	100%	11%	100%	75%
amp-in-url-test001 [APPROVED] (no description given)	Pass	Pass	Pass	Pass	no data	Pass	Pass
datatypes-test001 [APPROVED] A simple datatype production; a language+datatype production. Simply duplicate the constructs under http://www.w3.org/2000/10/rdf-tests/rdfcore/ntriples/test.nt	Fail	Pass	Pass	Pass	Pass	Pass	Pass
datatypes-test002 [APPROVED] A parser is not required to know about well-formed datatyped literals.	Pass	Pass	Pass	Pass	Pass	Pass	Undecided
rdf-charmod-literals-test001 [APPROVED] Does the treatment of literals conform to charmod ? Test for success of legal Normal Form C literal	Pass	Fail	Pass	Pass	Pass	Pass	Undecided
rdf-charmod-uris-test001 [APPROVED] A uriref is allowed to match non-US ASCII forms conforming to Unicode Normal Form C. No escaping algorithm is applied.	Pass	Fail	Pass	Pass	Pass	Pass	Undecided
rdf-charmod-uris-test002 [APPROVED] A uriref which already has % escaping is permitted. No unescaping algorithm is applied.	Pass	Pass	Pass	Pass	Pass	Pass	Pass
rdf-containers-syntax-vs-schema-test001 [APPROVED] (no description given)	Pass	Pass	Pass	Pass	no data	Pass	Pass
rdf-containers-syntax-vs-schema-test002 [APPROVED] (no description given)	Pass	Pass	Fail	Pass	no data	Pass	Pass
rdf-containers-syntax-vs-schema-test003 [APPROVED] (no description given)	Pass	Pass	Pass	Pass	no data	Pass	Pass

Fig. 3. RDF core test results (W3C, 2003).

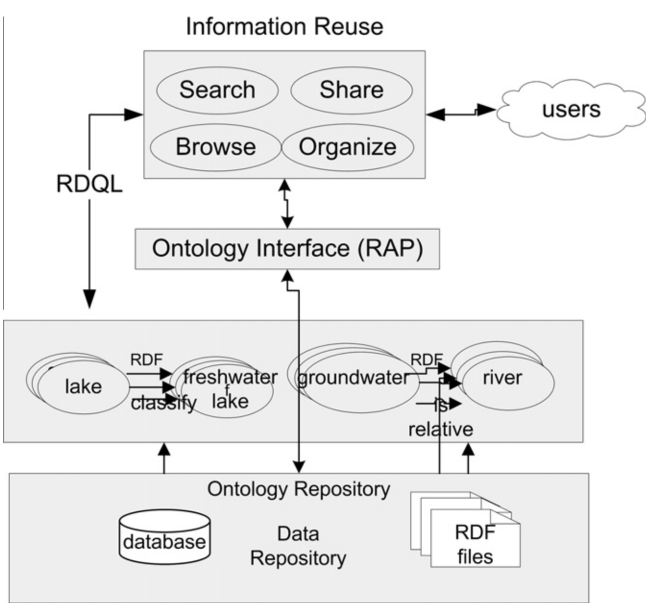

Fig. 4. CLS framework.

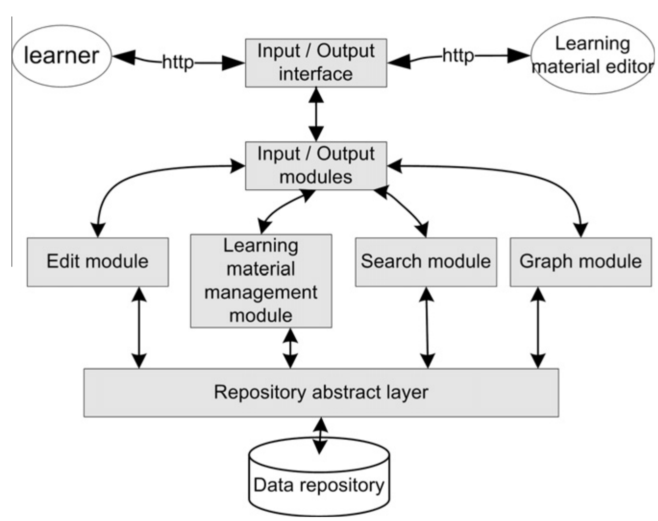

Fig. 5. CLS modules.

(1) Input/output interface is the interface that learners and learning material editors use to access the CLS.
(2) Input/output module is in charge of the user's authentication, log, and communication with other modules.
(3) Edit module converts the material plate file that is uploaded by teachers to the ontology file.
(4) Learning material management module presents and registers the materials and queries the user's learning progress.
(5) Search module searches all distributed learning materials and integrates these materials to output modules when they match the learner's demands.
(6) Graph module converts the data to a visual graph with the GraphViz dot utility.
(7) Repository abstract layer is a bridge between all modules and the data repository, which contains database and ontology data. The database stores the users' background data, learning logs, and material data; the ontology data include the course framework and material ontology files.

4.3. Features

The CLS provides different menus for users in different learning processes, and the teacher can change the RDF file to control the menu items and the course presentation. The full menu list is:

- Display course unit framework
- Select course unit
- Display course unit concept map
- Search concept map or concept

- Find relationships among lower-level nodes in the same unit
- Find relationships among predicates and lower-level nodes
- Search predicate
- Find relationships among root and nodes in different units
- Find common concept for different units
- Find common predicate node for different units
- Display users' learning logs

The CLS provides basic and advanced units for users, depending on their learning progress. Fig. 6 presents users' learning paths and completed units in the top screen. When users choose a learning unit, they see the learning content list that contains many concepts. When they select a concept list, detailed descriptions are displayed. When the user finishes one learning unit, the CLS shows the entire concept map graph (Fig. 1) to help the user to consolidate his or her cognitive structure.

The CLS provides a concepts lists and visual concept maps for every course unit (Fig. 7). The concept list on the left side depicts the relationship between any two concepts, and the right side indicates the concept's absolute location and hierarchy relationship among all the course concepts.

In order to help users to clarify their concept map, the CLS provides three relationships functions. Firstly, the user can find the relationships among the lower-level nodes in the same unit. Secondly, they can find the relationships among predicates and lower-level nodes. Finally, they can find the relationships among root and nodes in different units. By RDF triple searching, the CLS helps users realize and recall the learning paths between two concepts. When the user inputs the starting subject and destination object, the CLS lists and illustrates the concept learning paths. In the example in Fig. 8, the user wants to know the concepts from glacier to *Titanic*; the CLS shows that the glacier is classified as a continental glacier; a continental glacier melts to become an iceberg; an iceberg harms sailing ships; and the *Titanic* is an example of sailing ships. In addition, if the user inputs the "classify" predicate in the iceberg concept, the CLS lists the matching results (i.e., the mountain glacier and the continental glacier) and depicts the concept map in real time.

Fig. 6. Snapshot of the CLS.

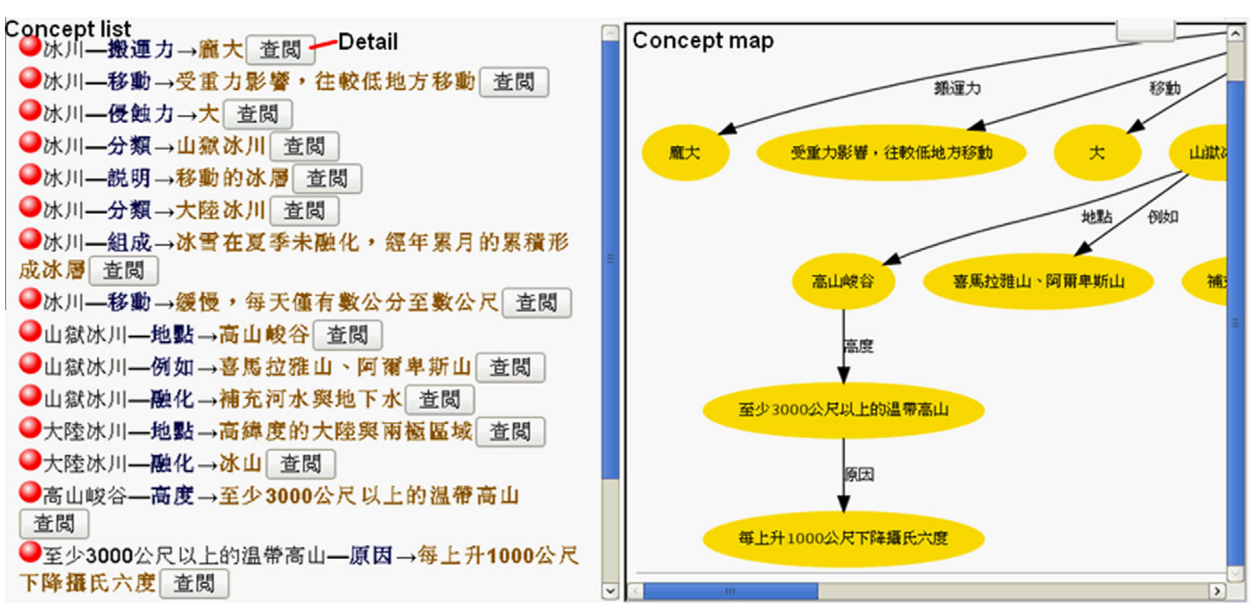

Fig. 7. Concept list and concept map.

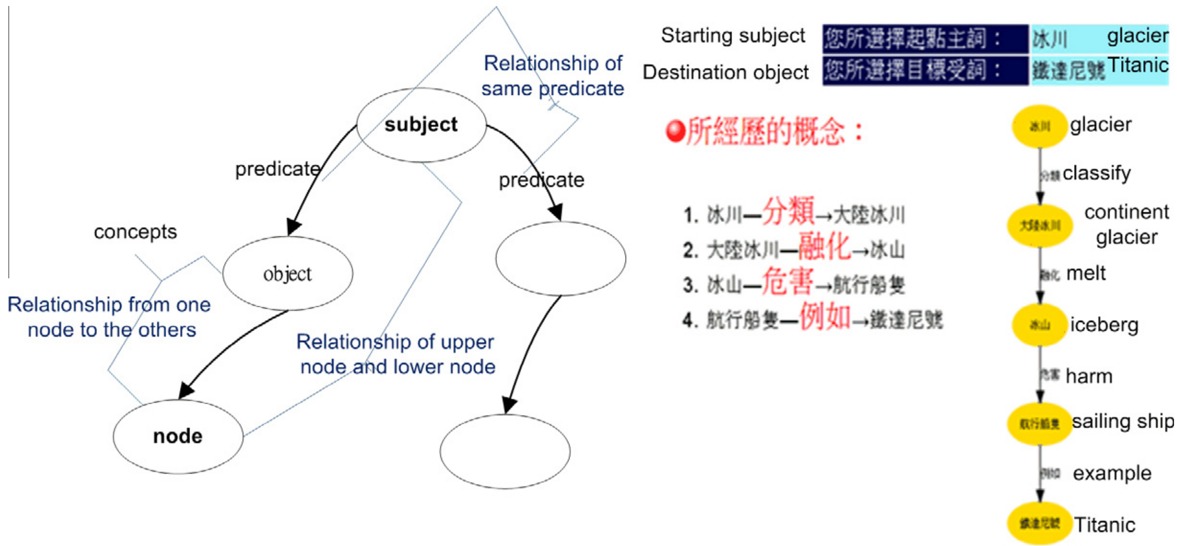

Fig. 8. Hierarchy of the learning path from one node to another.

Fig. 9. Common node for different units.

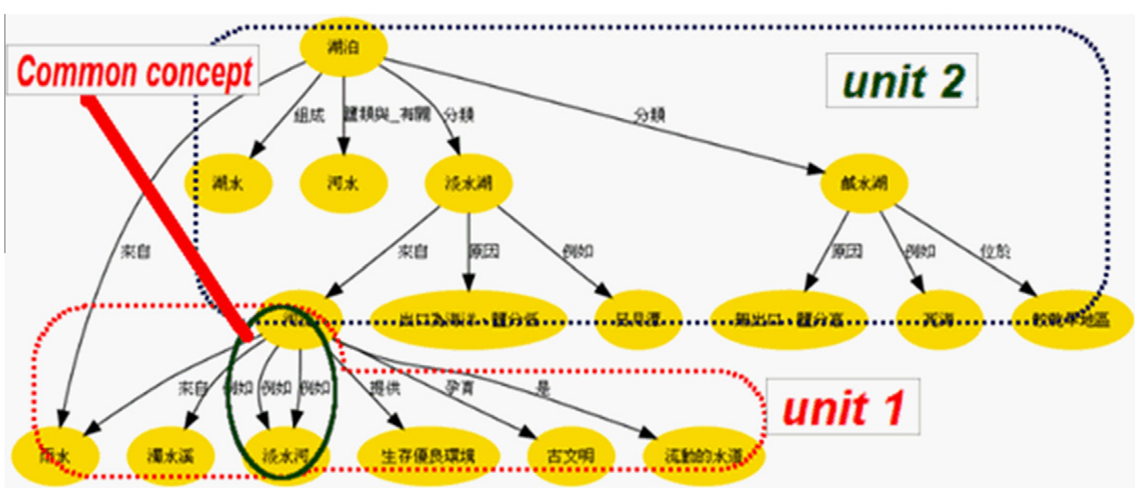

Fig. 10. Common concept for different units.

The CLS can indicate the relationship between root and lower-level nodes of different units, so it is easy for users to learn that different units can be merged by the same node. For example, "water vapor" and "ocean" are different units, but they can be merged by the node "sea water" (Fig. 9). Likewise, two units can be merged by a common concept, which means they have the same subject, predicate, and object. For example, "lake" and "river" are two different units, with the intersection "river—example → Danshuei River" (Fig. 10).

To help the teacher to create an ontology database, the CLS provides an import interface to convert a plate file that is uploaded by the teacher to the RDF file and database. A plate file is a comma-separated values (CSV) file that includes subject, predicate, predicate English version, object, description, and picture URL (optional). Fig. 11 depicts the resulting RDF file after the CLS has converted the plate file.

The CLS records all users' learning histories, including the login count, learned concepts, and completed units; it also monitors

```
<!-- Generated by RdfSerializer.php from RDF RAP.
# http://www.wiwiss.fu-berlin.de/suhl/bizer/rdfapi/index.html !-->

<rdf:RDF
  xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
  xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
  xmlns:owl="http://www.w3.org/2002/07/owl#"
  xmlns:dc="http://purl.org/dc/elements/1.1/"
  xmlns:dcterms="http://purl.org/dc/terms/"
  xmlns:vcard="http://www.w3.org/2001/vcard-rdf/3.0#"
  xmlns:ns1="http://mylesson.tnc.edu.tw/">

<rdf:Description rdf:about="http://mylesson.tnc.edu.tw/水氣">
  <ns1:evaporate_from rdf:resource="http://mylesson.tnc.edu.tw/海水"/>
  <ns1:evaporate_from>河水</ns1:evaporate_from>
  <ns1:evaporate_from>湖水</ns1:evaporate_from>
  <ns1:evaporate_from>植物葉片</ns1:evaporate_from>
</rdf:Description>

</rdf:RDF>
```

Fig. 11. RDF file of course unit.

every learner's progress and automatically filters appropriate concepts to learners.

5. Discussion and conclusion

The CLS design follows Novak's meaningful learning theory, which asserts that learners must incorporate new concepts into the original knowledge structure and add a new node to the lower-level node or create a new node; thus, all learners must engage in meaningful learning. Collins and Brown (1988) stated that a great learning environment emphasizes the promotion and development of students' learning reflection. The CLS provides the concepts of course unit navigations, searching and matching concepts that help develop students' reflection and establish their full, detailed knowledge structure.

The CLS learning log records users' learning paths and login information, allowing teachers to monitor or track their students' learning progress. Teachers are able to diagnose students' cognitive disorientation. Evidence indicates that concept mapping enables learners to reduce their cognitive load and extend their simple memory (Jonassen, 1987; O'Donnell et al., 2002; Sweller, 1988, 1994), especially by dividing a course unit into many smaller concepts – a useful strategy that supports and fosters learners' cognitive comprehension in different teaching and learning scenarios, clarifies for learners the common concepts, and thus increases learners' transfer of learning. According to learning theories, the CLS includes many functions to make learning easy and efficient.

In order to implement an adaptive concept map learning system, we utilize ontology technology to implement the CLS. Thus far, we have used only the RDF searching function to create this prototype ontology-based concept map learning system. The most powerful reasoning functions of the ontology (e.g., checking consistency, classifying taxonomy, and computing inferred types) have not yet been implemented. We hope to achieve this goal in the future, so that the CLS will provide the most suitable learning material or concept to help users learn.

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