CogSkillnet: An Ontology-Based Representation of Cognitive Skills

Petek Askar and Arif Altun

Hacettepe University Dept. of Computer Education and Instructional Technologies // paskar@hacettepe.edu.tr // altunar@hacettepe.edu.tr

ABSTRACT
A number of studies emphasized the need to capture learners' interaction patterns in order to personalize their learning process as they study through learning objects. In education context, learning materials are designed based on pre-determined expectations and learners are evaluated to what extent they master these expectations. Representation of these expectations in learning and assessment objects, on the other hand, is a new challenge for e-learner providers. In order to address this challenge, POLEonto (Personlized Ontological Learning Environment) proposes a new method to separate these expectations by determining domain concepts (ConceptNet) and cognitive skills (CogSkillNet) for expectations via creating cognitive skill and concept ontology for K-12 education. In this paper, we report only the development and design processes of CogSkillNet within POLEonto environment; and, we further discuss how CogSkillNet can be modeled in the e-learning domain. We also describe how ontological representations play a role in creating personalized navigational guidance for allowing visualization of cognitive skills and providing useful navigational feedback to learners.

Keywords
Ontology, Ontology Development, Cognitive Skills, Educational Expectations, Instructional Design

Introduction

Semantic web opened a new paradigm to design adaptive e-learning systems. By using the capabilities of semantic web approach, World Wide Web led the interchange of information about data (i.e., metadata) as well as documents. Such capabilities also indicated a new kind of challenge for e-learning providers to design a common framework that allows learning objects to be shared and reused within and across applications.

An ontology is an explicit specification of a conceptualization (Gruber, 1995) or a model (Musen, 1998), which is used for structuring and modeling of a particular domain that is shared by a group of people in an organization (O'Leary, 1998). Domain ontologies provide explicit and formal descriptions of concepts in a domain of discourse, their properties, relationships among concepts and axioms (Guarino, 1995).

Ontologies are being developed in order to make learning objects reusable (Qin & Hernández, 2006), interoperable (Biletskiy & Hirtle, 2006), and to increase the reliability of using computational (intelligent) agents in e-learning environments (Koper & Tattersall, 2005). Consequently, an ontology design is needed to equip the learning objects with the ability of semantic relations among different types of objects in educational settings.

In order to model the semantic relationships, various models have been designed by various researchers and committees. In their model, for example, Bailey, et. al. (2006) use the nugget metaphor and focus on the need for assisting teachers in the thought processes involved in selecting appropriate methods, tools, student activities and assessments to suit the required learning objectives. Similarly, IMS Learning Design (LD) model proposes an application of a pedagogical model for a specific learning objective, target group, and a specific context or knowledge domain (See, Koper and Olivier, 2004). Another model is proposed by IEEE Learning Technology Standards Committee (LTSC). In this model, learning object metadata covers areas of learning technology, digital rights, metadata, and structured definitions related to instruction.

These attempts to model the learning processes invited several criticisms. For example, Paquette (2007) points out that the actors' competencies in IMS-LD are indirectly defined in learning units or activities only if educational objectives are associated. Such unstructured model for competencies makes the system unable to provide personalized learning activities for its users, since this association between learning objects within a unit of learning is a key concept for semantic web applications (Berners-Lee, Hendler, & Lassilla, 2001). Waldman, Hopkins, & Burgess (2004), on the other hand, claim that the use of metadata in IEEE-LTSC model is based on metadata schemas, which are user-defined; therefore, reusability and interoperability of learning objects and the quality of user

created metadata became questionable. In addition, Murray (1998), in his model for distributed curriculum on the web, draws attention to certain pragmatic problems as well, among which are agreement on vocabulary for topics, terms (pedagogical aspects of the topics), subjective meaning for a term, differing context and limits.

In order to reach a more refined mechanism of matching what learners need and making inferences from users' interactions, some form of domain ontology (e.i., Davies, van Harmelan, & Fensel, 2002; Breuker, Muntjewerff, & Bredewej, 1999) and levels of mastering scales (e.i., Paquette, 2007) is needed. One of the approaches to determine the levels of mastering scales is to use existing taxonomies, such as Bloom (1956)'s taxonomy and apply the design axioms to make inferences from them. Another approach that is being proposed in this paper is to design an ontology representing the cognitive skills in the domain of education and describes the development and design processes of skill ontology, called CogSkillNet, which is an embedded agent in an e-learning environment.

Using an ontology to respresent and model the cognitive skills has several advantages over taxonomies. A taxonomy is a hierarchy and each skill is usually assigned a code within the hierarchy. In an e-learning environment, this code also encodes its path. Let's assume that in an educational expectation, a learner is requested to "analyze interpersonal communication". Certain cognitive skills can be grouped within the taxonomy of "to analyze" (in Bloom's taxonomy, to analyze covers to compare, to contrast, to deconstructs, and some others). By relating the learning objects with a cognitive skill in this taxonomy, it is possible to give this skill a certain amount of semantics. For example, when a learning object uses the skill "to compare" in order to describe its semantics, we can understand that this learning object is about "to analyze". Therefore, when a learner looking for a learning object to study how to "compare" can search for "to analyze" to obtain all related skills within the taxonomy. Note however that these skills might be referred in other skills within the taxonomy. For example, "to compare" as a skill is also included in "to evaluate" in Bloom's taxonomy. There can be several such properties like these skills within expectations and hence the learner has to go through all skills found to manually pick the skill that satisfies the expectations (or educational standards). In short, taxonomies do not help in this respect.

In this paper, we discuss the advantages of modeling the cognitive skills through ontology. We further note that, once the cognitive skills ontology is defined, it is also necessary to relate the defined ontology with concepts embedded in educational expectations within a learning space. Therefore, we describe how this can be achieved in an e-learning environment.

The paper is structured as follows: First, a background about using ontology in education is summarized. Second, the need for ontology in order to represent cognitive skills will be argued. Then, CogSkillNet ontology development process will be explained. Fourth, ontological representation of cognitive skills will be contextualized within K-12 educational expectation space. Finally, further recommendations for e-learning providers and researchers are stated.

Background

There are several ontologies being developed in the field of education. One of them is EduOnto. EduOnto is based on the metadata schemes for The Gateway to Educational Materials (http://www.thegateway.org/) and its controlled vocabulary. The class types include reusable classes (Person, Organization, and Contact), resource object classes (instructional, informational, research), and vocabulary classes (subject categories and terms) (Qin & Hernandes, 2006). Another ontology is Personalized Education Ontology (PEOnto). PEOnto claims to provide learners relevant learning objects based on their individual needs. In PEOnto, five interrelated educational ontologies (curriculum ontology, subject domain ontology, pedagogy ontology, people ontology, and personalized education agents) are being employed (Fok, 2006).

Another project is ELENA, which uses the metaphor of smart space for learning. ELENA claims to provide a personalized space for learners to meet learners' individual needs with available resources in educational meta repositories and services, such as brokering, learning, service evaluation and assessment services. ELENA includes a number of Personal Learning Assistants. These assistants use learner profiles to search for, select and negotiate with suitable learning services (Klobucar, Senicar, & Jerman-Blazic, 2004).

EML (Educational Modelling Language) is another system developed at the Open University of the Netherlands. EML focuses on representing: (a) the content of a unit of study (e.g., texts, tasks, assignments) and (b) "the roles,

relations, interactions and activities of students and teachers". EML goes beyond standards such as IEEE LOM to model the social context of education, and the learning, unit of study, domain, and learning theory models which form the pedagogic meta-model can be construed as a set of ontologies (Koper, 2001).

POLEonto is another ontology, which is still under development within POLE (Personalized Ontological Learning Environment) e-learning platform specifically for K-12 education. POLE is being conceptualized by the learning space metaphor (Altun & Askar, 2008), which represents the spatial dimension where learners navigate through the links in order to reach a destination in a given period of time. This learning space includes a combination of various skills (*any mental skills that are used in the process of acquiring knowledge*) and concepts (*contextualized terms within a domain and more specific than knowledge*) in defining (*or modeling*) an expectation or an education standard.

An educational expectation or a standard, set by either the board of education or instructors themselves, connotes something external, extrinsic, and explicit. Moreover, when these statements are written, internal ideas, objectives, and goals are put into external forms so that they can be shared with others (Seels & Glasgow, 1998). It is important to emphasize that instructors are expected to reach and to perceive the same meaning from these expectations and standards. In order to achieve this end, we propose a method to separate these expectations by deconstructing them as concepts and skills for each expectation via creating cognitive skills ontology (hereafter CogSkillNet) and concepts ontology (ConceptNet) separately in order to represent an expectation space from an ontic perspective (See Figure 1).
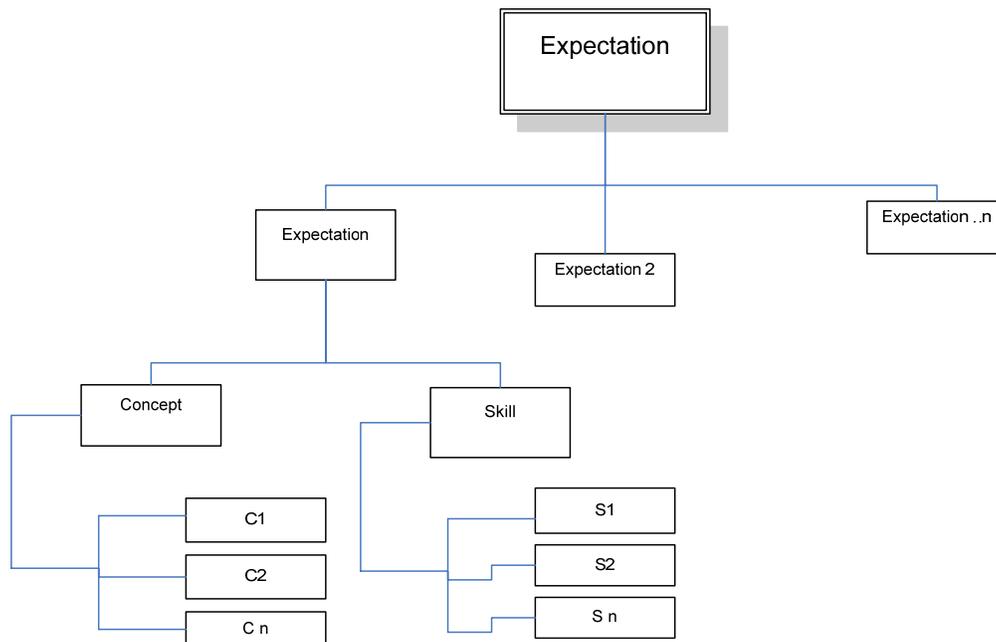

Figure 1. Deconstruction of an Education Expectation

In POLEonto, learning processes were defined as a set of cognitive skills, which were embedded in the curriculum and requested by instructors. In POLEonto context, skill is defined as the interaction and any processes between persons and concepts. For example, the concept of "square" is **envisioned** in one's mind; yet, they can **define** it, they can **extend** square into some other thing (i.e., a table or a flower-stand), which is **creative thinking**. The square can be manipulated to approach a problem by using its types and functions, which requires **problem solving**. In the following section, arguments for ontological representations for cognitive skills will be provoked and the methodology of CogSkillNet ontology development will be explained in detail.

Why is a need for ontology to represent cognitive skills?

CogSkillNet ontology has been proposed to address two major needs. First, the ontology design in an expectation-based education context includes concept space and skills space (See Figure 2). The elements in an expectation represent a conceptual model, which formally constraints the semantics of the concept taxonomy based on explanations formulated in natural language. Skills are dynamic in nature. Therefore, such dynamic relations are needed to be included in an ontology in order to show the execution of a skill within a cognitive process. Therefore, there is a need to define skills and their relational axioms in a dynamic approach.
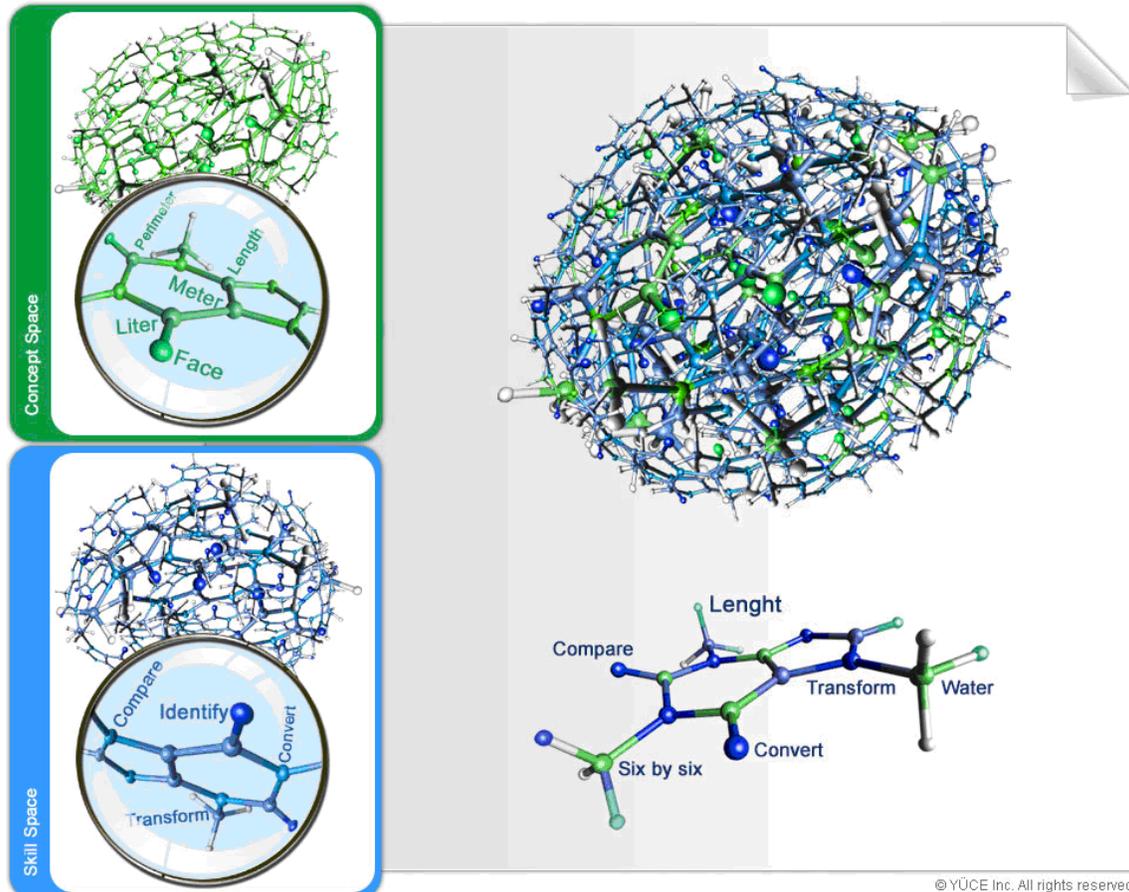
Figure 2. Structure of an expectation: Concepts and Skills

The second one is related to the architectural specifications. From the proposed specifications, the IMS Learning Design (IMS LD) (2003) has emerged as the de facto standard that addresses the ontological modeling of any specification for learning design. XML-Schema language is suggested and used when modeling the IMS LD specification in order to facilitate the interoperability between software systems.

CogSkillNet presents a new idea of modeling skills for educational context. In their comparison of conceptual modeling methods in databases (DB), knowledge representation formalisms (KB), and Semantic Web ontology languages (SW-onto), Ding, Kolari, Ding, Avancha, Finin, and Joshi (2006) assert that the Semantic Web significantly improves visibility and extensibility aspects of knowledge sharing in comparison with the previous approaches (See Figure 3). Its URI-based vocabulary and XML-based grammar are key enablers to web-scale knowledge management and sharing. Thus, by using semantic web ontology languages, CogSkillNet is aimed to increase usage, sharing and management of learning and assessment objects in educational contexts.
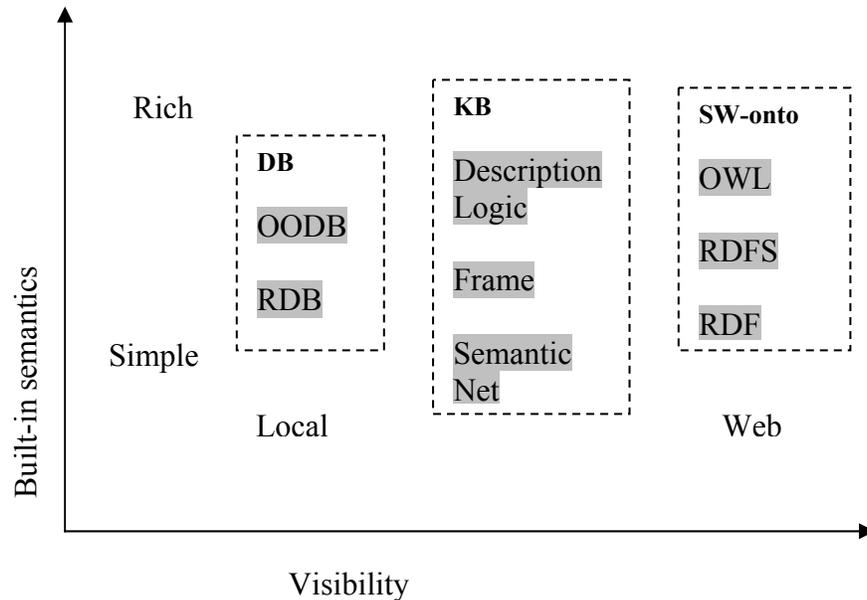
Figure 3. A comparison of knowledge representation formalisms (KB), conceptual modeling methods in databases (DB), and Semantic Web ontology languages (SW-onto)

Method

It is a well-accepted fact that there is not a single way of developing ontology (Noy & McGuinness, 2001). Building object-oriented applications with reusable learning objects based on semantic webbing techniques require a sequence of steps to build such an application (Askar, Altun, Kalinyazgan, & Pekince, 2007). In order to reach CogSkillNet ontology, a five-step ontology development process, with an iterative approach to ontology development, has been applied (adapted from McGuiness, 1999). These steps were:
1. Enumerate important terms in the ontology
2. Define the classes and the class hierarchy
3. Define the properties/relations of classes
4. Create Instances
5. Create axioms/rules

When designing the ontology, Protégé was used as an ontology editor. The visualizations are captured by TGViz and Jambalaya plug-ins embedded in Protégé. In the following section, these steps are explained in detail.

CogSkillNet Development Process

Enumerating Important Terms

A term in CogSkillNet refers to an entity, which represents a textual representation of a cognitive skill. Skills are conceptual representations of cognitive processes in an action. At the first step, important terms regarding the cognitive skills in K-12 educational curricula have been determined by using bootstrapping method. Bootstrapping is a technique that enables the designers to pull out their corpus from domain-specific corpora. These terms were clustered according to their functional and semantic relations based on pre-determined expectations in K-12 educational curricula. These clusters help disambiguate the repeated skills within each subject matter; for example, does the action word "state" in a document refer to an idea (i.e., liberal arts), a calculation result (i.e., mathematics), or a measurement (i.e., an interdisciplinary critical thinking activity). Consequently, when a single skill is repeated several times, semantic relations for each skill become evident.

Defining the classes and Class Hierarchy

The clusters obtained from bootstrapping represent the taxonomical classification of cognitive skills in an educational curriculum. Each learner, having completed the stated expectations successfully, is expected to reach a higher order thinking skill via planned instruction. In CogSkillNet, cognitive skills, or actions, are clustered in three hierarchical classes. These action classes are labeled as base actions, encapsulated actions and integrated actions. In CogSkillNet context, integrated actions represent higher order thinking skills such as problem solving, scientific thinking, and critical thinking. The following schema (Figure 4) represents the classes and class hierarchy for cognitive skills in education domain.
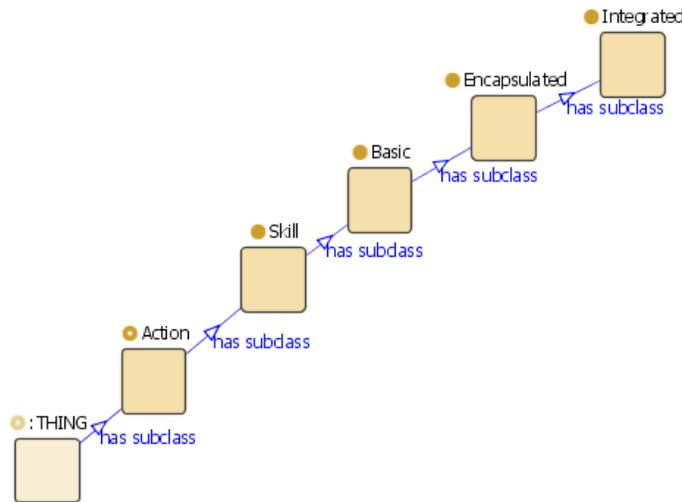

Figure 4. Class Hierarchy in CogSkillNet

Properties and Relations

For the next step, properties for these classes were defined by using implicit semantic techniques in order to find connections and patterns in the data (Askar, Altun, Kalinyazgan, & Pekince, 2007). This process was mainly used to generate and understand the relationships between entities in the selected context. In CogSkillNet, six different types of relations (with their inverses) were identified. These are:

    Y: is an instance of
    X: is a class of
    C: is a superClass of
    A: is a subClass of
    K: is a process_component of
    T: has process_component of

It should be noted that these relationships are dynamic in that they could be increased or limited in use depending on the content area within a curriculum

Creating Instances

Skills in CogSkillNet include actions, processes (aka relations and relation types) and delegations as instances. Base actions are pre-defined, universal sets of functions. These are axiomatized actions, which do not necessarily require logics or explanations, since they are self-exploratory command-like acts (i.e., *to identify*, *to show*, *to read)*. These actions both generate new actions from existing actions and validate the consistency of actions. These acts are processable, can be in the form of compound or simple forms; and, can be defined as visible or invisible.

Additionally, encapsulated actions are tacit processes in nature. These actions are organized from base actions in the form of input-process-output framework. Eventually, each action is designed to return an output. Consequently,

ontology will easily be extensible in an incremental manner by reusing as many existing actions as possible before creating a new action from scratch.

Integrated (Higher order) actions, on the other hand, are designed as tropes. They include certain encapsulated actions as well as base actions in order to fully accomplish the related process. These actions are processed depending on the related acts. Integrated Actions can be in Public or Private State. Public state includes all the process collection and includes the steps in the form of input-process-output framework, whereas Private states refer to attitudinal states, such as *to like*, *to enjoy*, etc., which are personal experiences in nature. Private state can be either delegated or non-delegated. Delegated actions are triggered when certain conditions are met. Non-delegated actions do not necessarily require certain conditions to be processed. The following figure represents the conceptual framework of instances in CogSkillNet (See Figure 5).
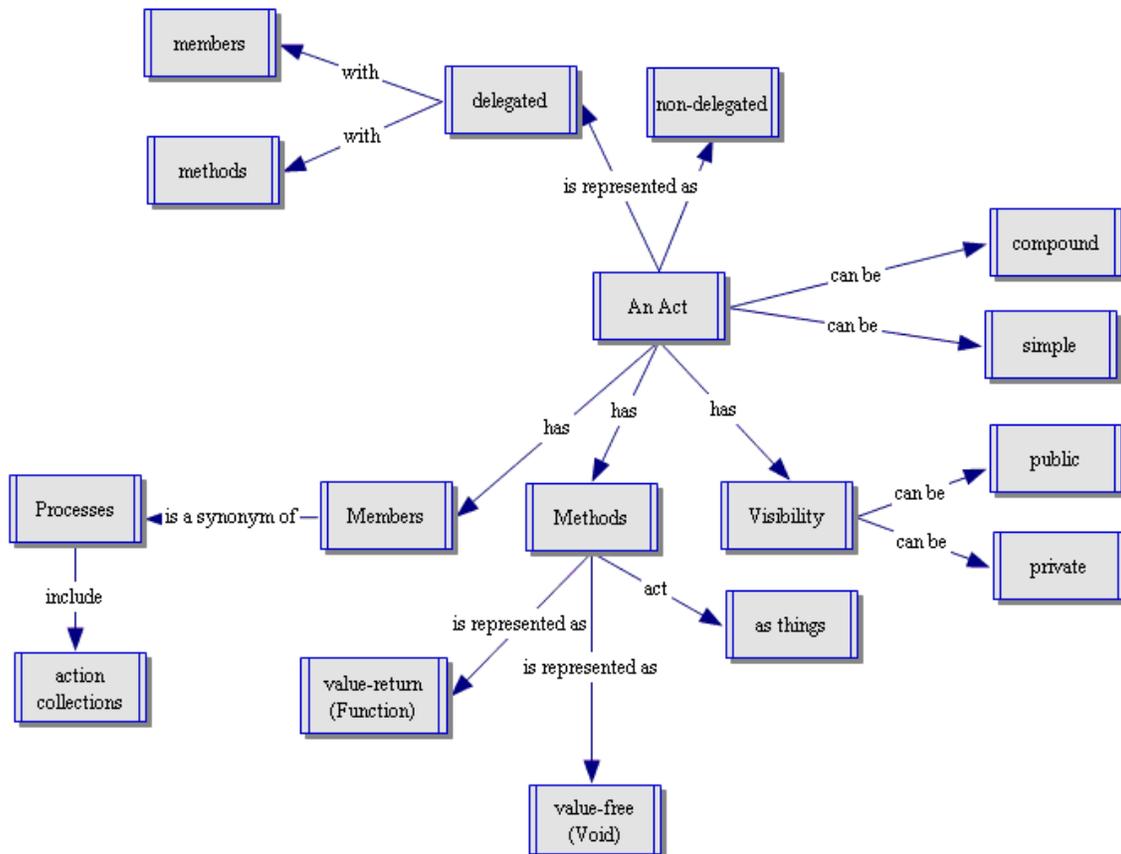

Figure 5. Conceptual Framework of Instances

Setting Axioms/Rules

As a next step, a series of axioms were developed for CogSkillNet. The axioms for the model take an action to be processed. In referring to figure 4, an action contains an act. Each act starts with an initiator as input, processes it, and terminates with an output. The process may have one or more sub-actions. Actions in the CogSkillNet apply the following axioms:
1. Each action can be acted upon.
2. Each action can contain actions (sub-actions).
3. Each action can call all actions' acts while acting.
4. Each act operates on input and returns output.
5. A returned output in each process is transferred to the next coming act as an input.
6. The output from the last act in the process is the input of the corresponding act.
7. The inputs and outputs can be Null, single, or multiple.

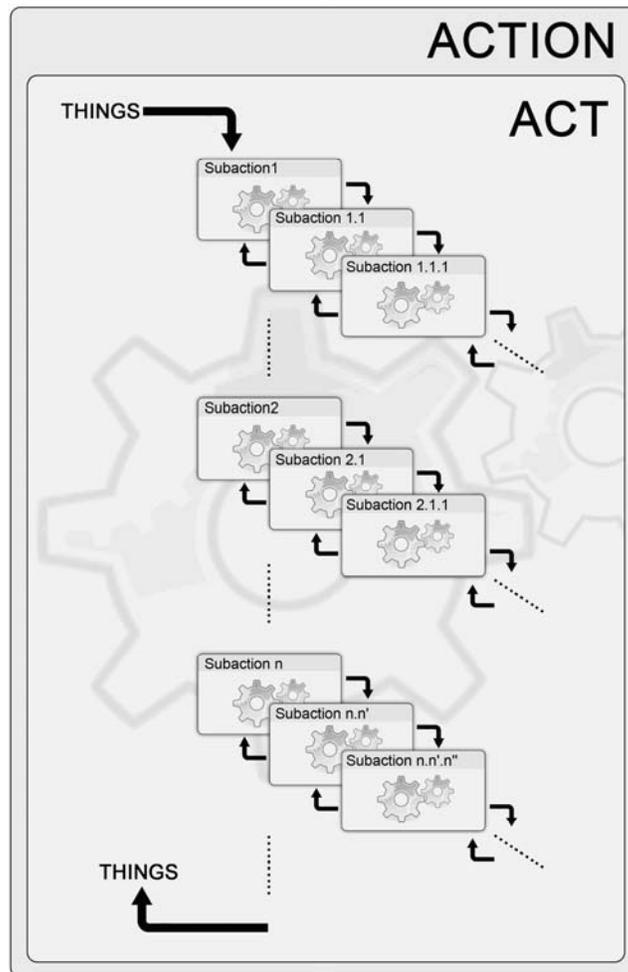The algorithm for this process can be modeled as in Figure 6.

Figure 6. Initiator-process-terminator (IPO) framework

IPO framework is necessary to contextualize the cognitive skills in an expectation space. All interaction in this framework represents actions, which are in the form of acts. These acts require an initiator and a terminator. Terminators provide input for any corresponding act; thus, they are transferred to the next coming act as input. Acts are processed until all related sub-actions are completed. An educational expectation requires learners process certain skills based on pre-determined initiators, such as *a reading material* or *a list of statements*. Moreover, learners are required to communicate their terminated process either with their peers or with instructors, such as ***writing a report*** or ***delivering an oral presentation***. This combination of initiators and terminators with corresponding cognitive skills (let's say to summarize) in the ontology constitute the context of each educational expectation (or goal).

Visual Representation of Cognitive Skills and CogSkillNet Algorithm

By taking into account all the considerations described above, ontology for the cognitive skills has been designed. The main parts of the ontology include actions and concepts as two different classes. Action class represents basic, encapsulated and integrated skills; whereas, concept class includes instances for initiators (input) and terminators (output) to be processed. In addition, depending on the stated relationship, Boolean and Question types were included within the ontology to activate rules and axioms in order to make further inferences. The following diagram displays a quasi-algorithm of cognitive skills within CogSkillNet (See Figure 7).
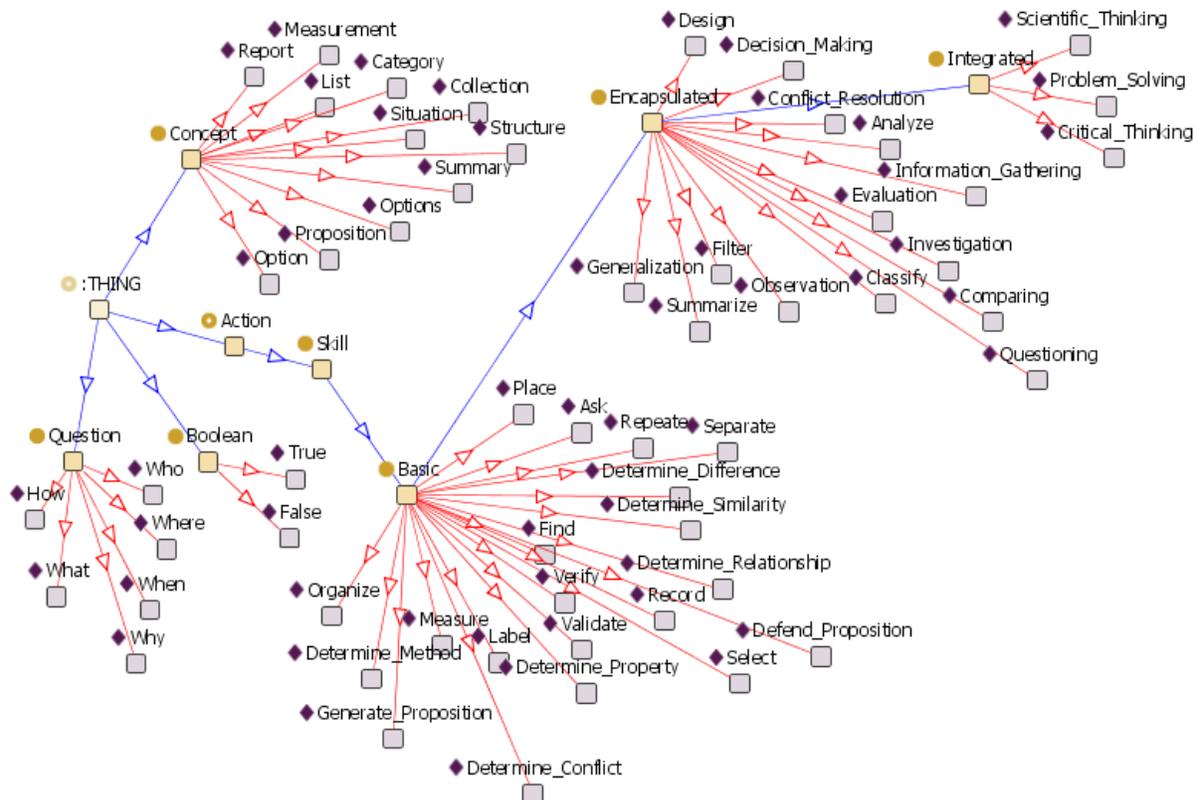
Figure 7. Visual Representation of CogSkillNet

An essential part of the ontology is the representation of skills in an expectation. In order to determine students' cognitive performances and to provide them meaningful learning paths, expectations are tied with assessment and learning objects. Thus, CogSkillNet represents and operates on the cognitive skills in line with assessment and learning objects in an e-learning environment (See Figure 8).

In an e-learning environment, each expectation may be associated with learning and assessment objects. Assessment objects represent what learners have accomplished whereas learning objects indicate units of learning materials. By incorporating CogSkillNet, the system will be able to identify the types of and the context for actions for learners. Types of actions refer to action classes (base, encapsulated, or integrated). Furthermore, by means of the declared axioms, the system would provide suggestions to learners which paths to continue. The context for actions, on the other hand, represents the concepts when to initiate and terminate the actions. For example, let's consider the skill "generalization". The initiation for generalization can be a "proposition" or a "list" as input depending on the content of a learning or assessment object. Additionally, generalization leads to produce an output, such as a "statement" or an "argumentation". These concepts indicate a termination of generalization. Altogether, (generalization, statements, and propositions) these concept and cognitive skill classes create a context of learning in an educational domain. The numbers of initiators and terminators can be numerous and provide different contextual information for each cognitive skill.

The action algorithm for basic actions is self-exploratory. In other words, if the input includes a base action, the system will provide either a learning or assessment object related to a single base action. Action algorithm for encapsulated and integrated actions, however, is as follows:

Action Algorithm for encapsulated and integrated actions
        Input: An Educational Expectation
        Output: Suggestion of a learning path

        Step1: Determine the action

Step 2: Determine the type of the action
Step 3: If encapsulated or integrated
       Then get the Sub-actions
       Repeat until all sub-actions are processed
       Loop all actions until reaches to base actions
       Else
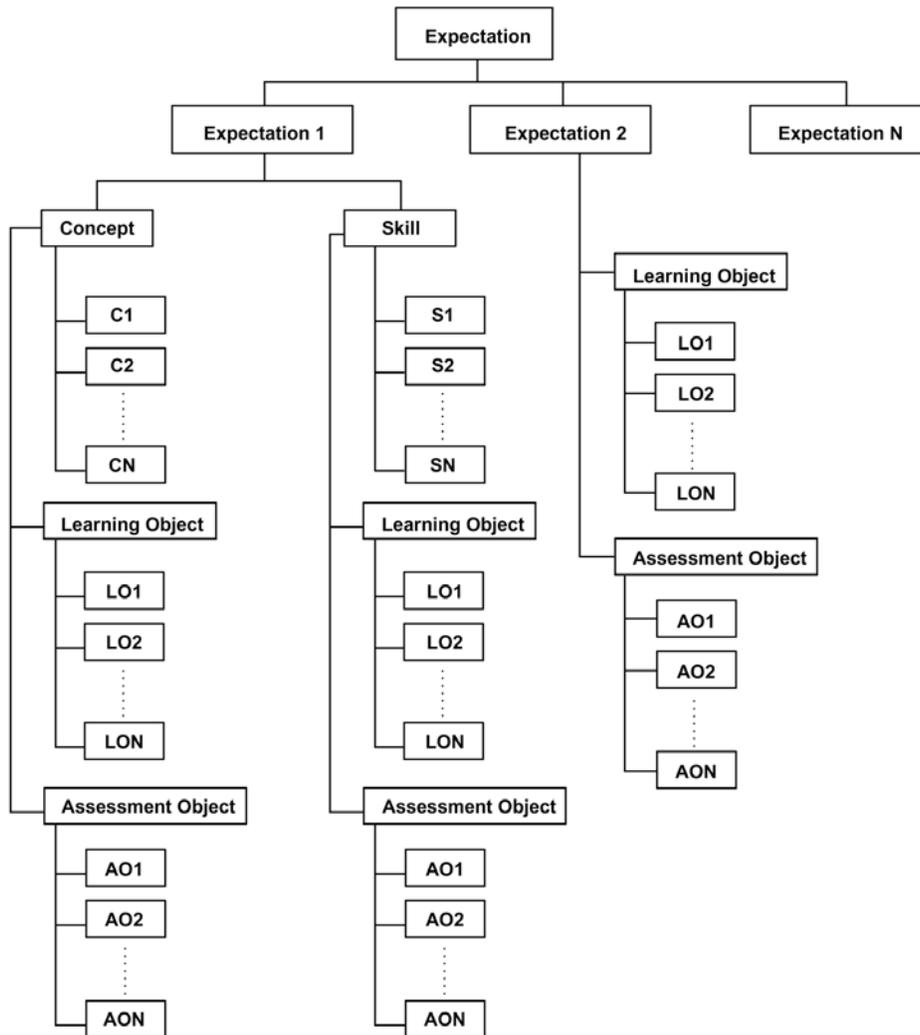   Base actions

Figure 8. Learning and Assessment Objects in an Expectation Space

Furthermore, the system further contextualizes the educational expectations (See Figure 9) by incorporating the nature of actions into the process as shown in the following algorithm.

Input: Contextualize the expectation
Output: Contextualized e-learning environment

Step 1: Determine the action
Step 2: Determine the nature of actions
Step 3: Get the initiators
Step 4: Get the terminators

Step 5: Use Boolean to combine the initiators and terminators with actions
Step 5: Determine the context
Step 6: If context is multiple
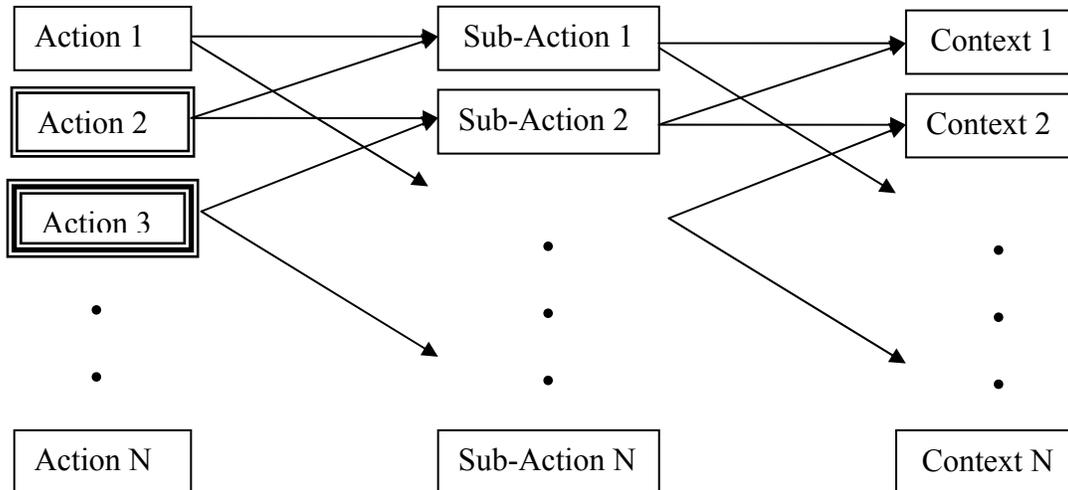　　　　Then provide pathways accordingly
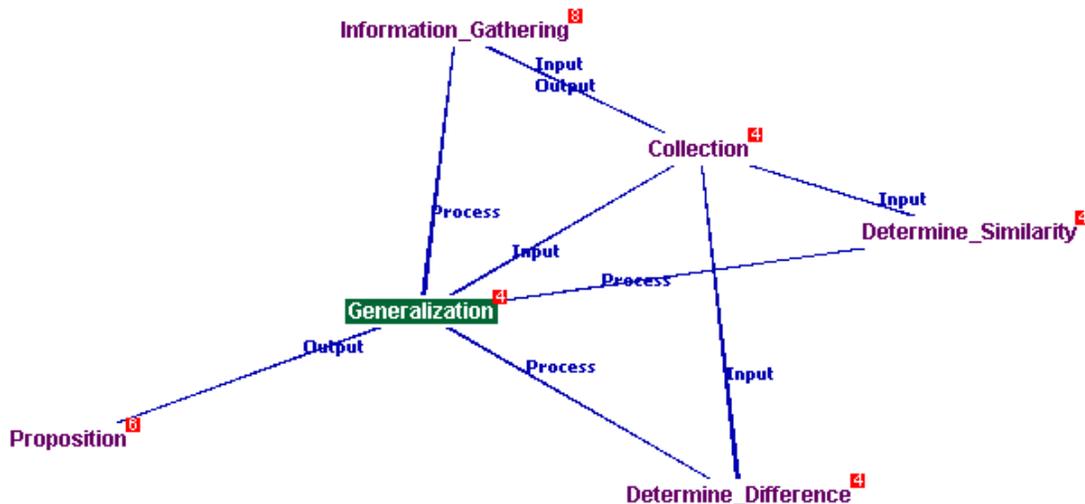

Figure 9. The structure of action processes

Figure 10. A Sample View from CogSkillNet

Let's illustrate this with an example. Let's assume a student is given a task (either as in an LO or as an AO) to *make a generalization* either in an assessment object or in a learning object to study. Generalization as a cognitive skill is not self-exploratory but tacit by itself. Since it is not a base action, it includes sub-processes and it is difficult for a student to analyze this process by himself/herself. If the system provides the learners sub-processes of generalization, which are information gathering, determining similarities and determining differences, the task will be more explicit for the learner to process as in the following algorithm.

Input: An Expectation (i.e., students learn to generalize the principles of sliding frictions)
Output: Suggest learning paths based on learners' progress and responses

Step 1: Check the action in the expectation
Step 2: Determine its class
Step 3: If encapsulated or integrated
   Then get the instances of each action within the class

Figure 10 visualizes the graphical representation of generalization.

As visualized above, generalization has_process_component of (a) Information Gathering, (b) Determine_similarity, and (c) Determine_Difference in CogSkillNet. Moreover, the system can further suggest the learner other cognitive skills by using the CogSkillNet relations and axioms. Determining differences, for example, will be needed to do comparisons, which is_a_process_component of decision making. In addition, the actions "Generalize", "Information Gathering", "Determine Difference", and "Comparing" may need a "Collection" as initiator and only "Information Gathering" returns a "collection" as terminator. The following figure (Figure 11) is a visual representation of this ontic relationship.
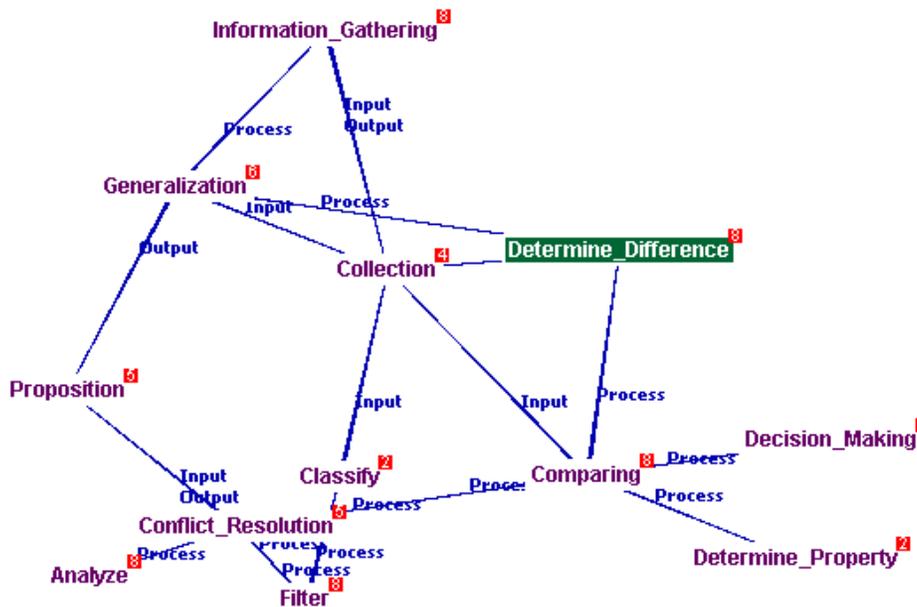

Figure 11. Determine Difference as an instance in CogSkillNet

Consequently, the system will be able to provide a personalized path for each learner based on his/her progress and/or responses.

Conclusion

This paper proposes an ontological representation of cognitive skills for K-12 education domain. CogSkillNet is one of the two ontologies -- the other one is concept ontology (ConceptNet) -- embedded in POLE e-learning system. Along with the concept ontology, CogSkillNet models the cognitive skills, which are associated with two repositories (learning object repository and assessment object repository) and are embedded in K-12 curriculum and requested by instructors.

On the basis of CogSkillNet, this study proposes the following contributions;
1) learners are provided navigation guidance for their learning path based on their progress through cognitive skills, which aim at scaffolding learning in a constructivist perspective.

2) CogSkillNet provides classroom instructors and instructional designers another tool when designing learning objects as well as other learning materials. These relations and representations of cognitive skills in an ontological space can further be used when making instructional decisions for classroom teaching.
3) CogSkillNet enables evaluators to base their assessment process and diagnose the deficiencies in students' learning as far as cognitive skills are concerned.

Many researchers hold the belief that the learning specifications, such as IEE LOM, IMS-LD and SCORM are of limited use in that prescriptive metadata have various drawbacks (See, Jovanović, Gašević, Knight, & Richards, 2007 *for detailed drawbacks*). Jovanović et. al. (2007) proposes the idea of creating a learning object context (LOC) as a unique set of inter-related data that characterize a specific learning situation. They go further to add that their LOCO framework integrates several kinds of learning-related ontologies in order to capture specific context of use. We believe that separating expectations as concepts and skills contribute to further extend the notion of context in use –within or without LOCO framework. As a result, more circular flow of information in the learning process can be maintained.

The cognitive skills of the proposed ontology, targeted for use by automated systems, can be embedded in standard metadata registries of learning and assesment objects to facilitate the design of instructional materials. In defining or adding the new skills to CogSkillNet, we have based these skills on an *Action* upper-class, under which any action, regardless of having input and/or output, can be placed easily. Moreover, using the *Concept* class within CogSkillNet, any further concepts can easily be integrated or added to the existing ontology.

The success of any e-learning environment depends highly on instructors' and learners' interactions between the system and themselves. We hope that the proposed ontology in this paper leads to more work towards the formalization of the knowledge about cognitive skills and its interdependent use with concepts in e-learning environments. Therefore, future research should address a complete review of the skills in the proposed ontology by domain experts in the creation and design of learning objects in K-12 education. In addition, separating expectations as concepts and skills and combining them in domain ontology is a new perspective for education ontology design. More research is needed to test the efficiency and accuracy of using this design, especially when sequencing, searching, and contextualizing learning objects, for e-learning platforms.

Acknowledgement

References

Altun, A., & Askar, P. (2008). An Ontological Approach to Designing Learning Objects. *Paper presented at the E-Learn Conference*, Nov 17-21, Las Vegas: Nevada, USA.

Askar, P., Kalinyazgan, K., Altun, A., & Pekince, S. S. (2007). An Ontology driven model for e-learning in K-12 education. In T. Kidd & H. Song (Eds.), *Handbook of Research on Instructional Systems and Technology* (pp. 105–114), Hershey, PA: Idea Group Reference.

Bailey, C., Zalfan, M. T, Davis, H. C., Fill, K., & Conole, G. (2006). Panning for Gold: Designing Pedagogically-inspired Learning Nuggets. *Educational Technology & Society, 9* (1), 113–122.

Berners-Lee, T., Hendler, J., & Lassilla, O. (2001). *The Semantic Web*. Retrieved March 2, 2009 from http://www.scientificamerican.com/article.cfm?articleID=00048144-10D2-1C70-84A9809EC588EF21&catID=2.

Biletskiy, Y., & Hirtle, D. (2006). Conceptualization of Specifying Learning Objects. *SEAS Transaction on Computers, 1* (5), 177–185.

Bloom, B. S. (1956). *Taxonomy of Educational Objectives: the Classification of Educational Goals*, NY: D. McKay.

Breuker, J., Muntjewerff, A., & Bredewej, B. (1999). Ontological modelling for designing educational systems. *Paper presented at the AI-ED 99 Workshop on Ontologies for Educational Systems*, July 18-19, Le Mans, France.

Davies, J., Harmelen, F. v., & Fensel, D. (2002). *Towards the semantic web: Ontology-driven knowledge management*, New York, NY: John Wiley.

Ding, L., Kolari, P., Ding, Z., & Avancha, S. (2006). Using Ontologies in the Semantic Web: A Survey. In R. Sharman, R. Kishore, & R. Ramesh (Eds.), *Ontologies: A Handbook of Principles, Concepts and Applications in Information Systems* (pp. 79–114), Berlin: Springer.

Fok, A. W. P. (2006). PEOnto – Integration of Multiple Ontologies for Personalized Learning. *Proceedings of the 5th IASTED international conference on Web-based education* (pp. 88-93), Anaheim, CA: ACTA Press.

Gruber, T. R. (1993). Toward principles for the design of ontologies used for knowledge sharing. *International Journal of Human-Computer Studies, 43* (5-6), 907–928.

Guarino, N. (1995). Formal ontology, conceptual analysis and knowledge representation. *International Journal of Human–Computer Studies, 43* (5-6), 625–640.

IMS-LD (2003). *IMS learning design: Information model, best practice and implementation guide,* Retrieved March 2, 2009 from http://www.imsglobal.org/learningdesign/index.cfm.

Jovanović, J., Gašević, D., Knight, C., & Richards, G. (2007). Ontologies for Effective Use of Context in e-Learning Settings. *Educational Technology & Society, 10* (3), 47–59.

Klobucar, T., Senicar, V., & Jerman-Blazic, B. (2004). Privacy and personalization in a Smart Pace for Learning. *International Journal of Continuing Engineering Education and Lifelong Learning, 14* (4–5), 388–401.

Koper, R. (2001). *Modeling units of study from a pedagogical perspective: the pedagogical meta-model behind EML. Version 2.* Retrieved March 2, 2009 from http://hdl.handle.net/1820/36.

Koper, R., & Oliver, B. (2004). Representing the learning design of units of learning. *Educational Technology and Society, 7* (3), 97–111.

Koper, R., & Tattersall, C. (2005). *Learning Design: A Handbook on Modelling and Delivering Networked Education and Training*, Berlin: Springer.

McGuinness, D. L. (1999). Ontologies for Electronic Commerce. *Proceedings of the Artificial Intelligence for Electronic Commerce Workshop of the AAAI National Conference*, Menlo Park, CA: AAAI Press.

Murray, T. (1998). A Model for Distributed Curriculum on the World Wide Web. *Journal of Interactive Media in Education, 98* (5), Retrieved March 2, 2009 from http://www-jime.open.ac.uk/98/5.

Musen, M. A. (1998). Modern architectures for intelligent systems: Reusable ontologies and problem-solving methods. In C.G. Chute (Ed.), Proceedings of the 1998 AMIA Annual Symposium (pp. 46-52), Orlando, FL, USA.

Noy, N. F., & McGuinness, D. L. (2001). *Ontology Development 101: A Guide to Create Your First Ontology*, Stanford Knowledge Systems Laboratory Technical Report KSL-01-05 and Stanford Medical Informatics Technical Report SMI-2001-0880, Stanford: Stanford University.

O'Leary, D. E. (1998). Using AI in Knowledge Management: Knowledge Bases and Ontologies. *IEEE Intelligent Systems, 13* (3), 34–39.

Paquette, G. (2007). An Ontology and a Software Framework for Competency Modeling and Management. *Educational Technology & Society, 10* (3), 1–21.

Qin, J., & Hernández, N. (2006). Building interoperable vocabulary and structures for learning objects. *Journal of the American Society for Information Science and Technology, 57* (2), 280–292.

Seels, B., & Glasgow, Z. (l998). *Making instructional design decisions* (2nd Ed.), Upper Saddle River, NJ: Prentice Hall.

Waldman, J., Hopkins, T., & Burgess, H. (2004). *Accreditation of prior certificated and experiential learning in new social work degree courses in England: a preliminary enquiry*, York, UK: The Higher Education Academy.