Scientia
Interdisciplinary Studies in Computer Science
19(1): 60-67, January/June 2008

Research directions on Semantic Web and education

Ig Ibert Bittencourt[1,2], Seiji Isotani[3], Evandro Costa[2], Riichiro Mizoguchi[3]

[1]Federal University of Campina Grande
Rua Aprigio Veloso, 882, Bodocongo, 58109-900, Campina Grande, PB, Brazil

[2]Computing Institute - Federal University of Alagoas
Campus A. C. Simões, BR 104 - Norte, Km 97, C. Universitária, Maceió, AL, Brazil

[3]Osaka University
8-1 Mihogaoka, Ibaraki, Osaka, 567-0047, Japan

ibert@dsc.ufcg.edu.br, evandro@fapeal.br, {isotani, miz}@ei.sanken.osaka-u.ac.jp

Abstract
Educational systems are gradually incorporating semantic web technologies aiming to provide a more adaptable, personalized and intelligent learning environment. In fact, there is a significant interest within the AIED community about the evolution of e-learning in this direction. This is driven by the hope that the use of Semantic Web (SW) technologies in educational systems can help the accomplishment of AAAL: Anytime, Anywhere, Anybody Learning where most of the WWW resources are reusable learning objects supported by standard technologies and learning is facilitated by intelligent pedagogical agents. Motivated by this trend, our paper presents an overview of the field of the Semantic Web in Education considering some of the main research challenges, architecture and standards, and showing how the use of ontologies can enhance the potential for making AAAL really meaningful to the learners in the SW era.

KEY WORDS: Web-based Educational Systems, Semantic Web, Semantic Web Services, Ontologies.

1 Introduction

Research related to web-based educational systems has been playing an important role in the improvement of the quality of services, such as the quality of educational content, pedagogical approaches in e-learning environments and technological frameworks (Vouk *et al.*, 1999). Although the first generation of web-based educational systems was marked by the influences of computer aided instruction (CAI) approach (forming the so-called Learning Management Systems), recently, the design of web-based learning systems started to move in a direction that joins the main concerns and results of the artificial intelligence in education (AIED) field. Nowadays, web-based systems are facing challenges that include: extensibility, interoperability, the use of domain ontologies, contextualization and consistence of metadata, dynamic sequencing of learning and contents, integration and reuse of content, distribution of services, new models of learning, and so on (Brooks *et al.*, 2006). Such challenges are related to the attempt to represent the information on the Web in a way that computers can understand and manipulate it. Research in this direction is known as Semantic Web research.

Semantic Web-based educational systems (SWBES) is the name given by the AI in Education community to the new generation of such systems that use semantic web technologies to generate educational systems that are more personalized, adaptable and intelligent. The main goal is to use resources available on the Web through standards-based technologies in order to accomplish AAAL: Anytime, Anywhere, Anybody Learning.

This paper presents an overview of the Semantic Web and Education field by considering its main research directions and challenges related to knowledge representation, architectures, technologies, and applications. Special attention is given to the topics on ontologies and pedagogical sound learning applications, yielding the new generation of intelligent e-learning systems. Part of the research in this area includes topics such as: building ontologies for e-learning; using ontologies and Semantic Web standards for structuring, representing, indexing, and retrieving shareable and interoperable learning resources; using ontologies and Semantic Web standards for supporting authoring of intelligent e-learning systems; using Semantic Web-based

contexts for adaptation and personalization of e-learning applications.

This paper is organized as it follows. Section 2 presents an overview of Semantic Web-based Education. Further details about research and applications are discussed in Section 3. Section 4 shows some of the challenges and future directions of Semantic Web in Education. Finally, conclusions and references are presented.

2 Semantic Web based education

Roughly speaking, Semantic Web (SW) extends the classical Web by providing it with a semantic structure of web pages to give support to human and artificial agents to understand the content. As a result, the Semantic Web provides an environment where software agents can navigate through Web documents and execute sophisticated tasks. SW enables numerous improvements in the context of Web-based education systems contributing to the upgrade of learning quality. Indeed, it can provide personalized learning material for students, collect data related to the interaction between students and the Web environment, find out services according to students needs, make recommendations, among others.

According to Anderson and Whitelock (2004), the Educational Semantic Web is based on three fundamental affordances. The first is the capacity for effective information storage and retrieval. The second is the capacity for non-human autonomous agents to augment the learning and information retrieval of human beings. The third affordance is the capacity of the Internet to support, extend and expand communication capabilities of humans in multiple formats across the bounds of time and space.

In general, a broad question concerning SWBES is the one involving the interaction among at least two players, a machine/Educational System (responsible for providing information according to a learning context or learning domain) and a user (with a specific role). Figure 1 describes a reference model of a Semantic Web-based Educational System.

The components of the Semantic Web-based Educational Systems are discussed below:

• Roles: several educational activities are involved in Semantic Web-based Educational systems, such as teaching, learning, cooperation, collaboration, authoring, and so on. Moreover, these activities are distributed according to the role of each player. Some of them can be described as it follows: (a) Teacher's Role: teachers are required to provide learning content and design learning activities, to monitor learners' interactions (problem solving, assessment, etc.), to configure learners' strategies, to support students' evaluation, etc.; (b) Learner's Role: the main interest of learners is to interact with the system in order to receive personalized educational content in order to improve their knowledge and fulfil their learning goals; (c) Author's Role: authors are responsible for structuring the educational content. Authoring activities are concerned with (i) educational content, (ii) instructional process, and (iii) adaptation and personalization (Aroyo and Dicheva, 2004); (d) Group's Role: the learning process can take place in groups. Group members are interested in collaborative learning, interaction with other students in order to reach personal goals, and in sharing cognitive, meta-cognitive, motivational, and emotional functions with other learners;

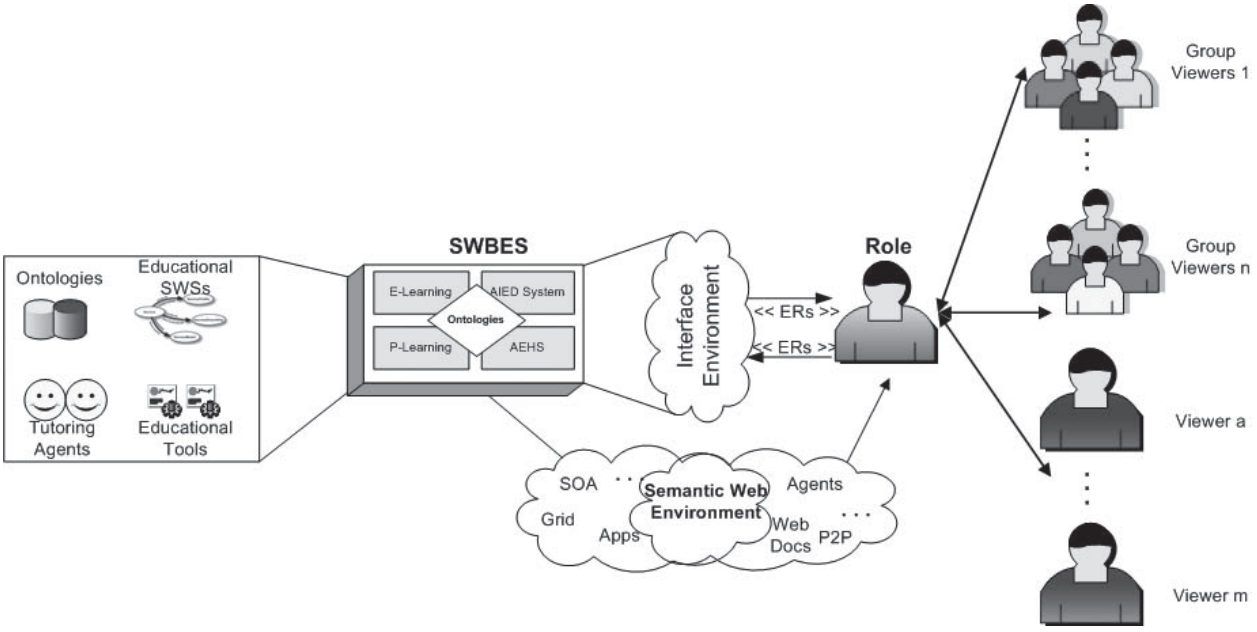

Figure 1. Reference Model of Semantic Web-based Educational systems.

(e) Developer's Role: developers are responsible for developing and adding new functionalities to the SWBES.

- Interface Environment: it represents the communication interface between a user with a specific role and the Semantic Web-based system. In addition, the context and the type of educational resources are important aspects that need to be considered when selecting the technology to be utilized in the environment. Another important point is that the Interface Environment has to support the different roles, thus providing specialized interfaces of the authoring tools, mobile tools, development/ framework environment, etc.;
- Educational Resources (ERs): educational resources represent the resources invoked by users in the interaction with the SWBES. They also have to be personalized according to the specific user roles. Examples of educational resources are learning objects (such as examples, problems, counter-examples, units of activities, etc.), educational ontologies, and others;
- SWBES: it supports the numerous users in an effective way by guiding and helping them to reach their educational goals. Thus, it represents the new generation of Web-based Educational Systems that aim at providing several improvements on the Quality of Services (QoS) through the use of Semantic Web technology. A SWBES includes:
  - Ontologies: they are used and addressed by the community as an important requirement to define content semantics, assure the interoperability between educational systems, etc.;
  - Tutoring Agents (or pedagogical agents): these agents help the learning process in several ways, for example, they can evaluate similarities between profiles, recommend educational content, compose semantic web services for education, etc;
  - Tools: several tools can be used in a Web-based educational system, such as collaborative tools, simulation tools, intelligent tools, and authoring tools;
  - Services: Semantic Web Services (SWS) can support a number of different educational activities transforming a static collection of information into a distributed one on the basis of Semantic Web technologies that make WWW content machine-processable and machine-interpretable. Examples of services for personalization of educational content and interfaces, assessment, collaboration, recommendation, etc.
- Semantic Web Environment: it represents the interaction environment available (to SWBESs and users) to discover, browse, select, and invoke semantically annotated resources on the Web by employing semantic technologies and architectures.

3 Research and applications

This section aims to provide a general view about the research on Semantic Web and Education, more specifically, a discussion with regards to architectures, standards, ontologies and applications.

3.1 Architectures

An architecture in our context represents a model conceived to a kind of SWBES, such as Learning Management Systems, Intelligent Tutoring Systems, Adaptive Educational Hypermedia Systems, Pervasive Learning Systems, among others (Costa and Bittencourt, 2007). In fact, it is one of the first issues to be considered by the stakeholders[1] involved in the construction of an application for providing information support from multiple perspectives. Thus, software engineering techniques should be considered to assure that necessary requirements in SWBES, for instance, extensibility, authoring, and reusability, will be embedded to guarantee the quality of learning and services. Some efforts in this area are described in Bittencourt *et al.* (2007), Milanovic *et al.* (2007), Dong (2004) and Motta and Sabou (2006).

Of interest are also the approaches that can be used for defining a software architecture, such as Grid Computing, Peer-to-peer and agents and Web Services. These approaches are related to: (a) the organization and structure of educational systems and content; (b) performance; (c) automatic composition; (d) intelligent reasoning, etc. Another important point is the research conducted by the SW community regarding semantic web services as an option for automating the integration of activities through creation, automatic discovering, and

[1] The term stakeholder generalizes the traditional notion of user in requirements engineering to all parties involved in a system's requirements (Glinz and Wieringa, 2007).

automatic composition (Al-Masri and Mahmoud, 2007; Brambilla *et al.*, 2007; Cardoso, 2006). From an education point of view, they will facilitate some educational activities, such as integration of content, discovery of educational resources, evaluation and comparison between educational applications, etc. According to Shafiq *et al*. (2006) the next generation of Web services - Semantic Web services - envisions Web services to be dynamically discovered, composed, invoked and executed.

3.2 Standards

The use of standards is fundamental in describing, developing, exchanging, accessing, annotating, combining and qualifying educational resources. Both Semantic Web standards (e.g., RDF, 2008; SKOS, 2008) and educational resources (e.g., IEEE, 2008; IMS, 2008) are used in the development of SWBES (Dietze *et al.*, 2007; Gasevic *et al.*, 2004).

According to Devedzic (2006), in the context of Educational Semantic Web, most of the practical implementations and usage of standards is related to learning object (LO) annotation, which creates a number of additional requirements for the successful use of standards. The development of simple methods and tools for LO annotation, differentiation between objective and subjective metadata, combination metadata sets and schemes from multiple sources, seamless integration of production and annotation, introduction of formal semantics into existing standards, and a flexible and dynamic association of metadata with LOs, are some of the challenges that the standards have been dealing with.

3.3 Ontologies

Information on the Web is commonly represented in natural-language for human understanding. However, in order for the computer to understand its meaning, it is necessary to represent the information in a form that can be interpreted syntactically and semantically. Such representation helps the process of analyzing, extracting, and integrating information on the Web, making it easier the creation of solid knowledge bases that intelligent services can rely on to support users' needs. Nowadays, research on ontologies has been considered one of the keys to provide information in a computer-understandable way (Mizoguchi, 2004). According to Devedzic (2006), the use of ontologies and the advent of intelligent services for developing Web content, Web filters, intelligent search engines, and other applications are transforming the Web of information into the Semantic Web (SW).

From an Artificial Intelligence point of view, ontology can be seen as "the basic structure or armature around which a knowledge base can be built" (Swartout and Tate, 1999). It means that ontologies try to explain how the world is configured by introducing a system of critical categories and their intrinsic relations which allows a shared understanding and semantic interoperability. It provides a set of fundamental concepts that includes the vocabulary, the semantic interconnections between concepts and simple rules of inference for some specific task or domain (Hendler, 2001).

The development and deployment of ontologies is not an easy task. It requires a sophisticated methodology, and still sometimes it is more an art rather than technology (Mizoguchi, 2004). In educational domain the problem of building ontologies has been tackled by different research groups providing many different approaches to deal with ontology development (Aroyo and Dicheva, 2004; Anderson and Whitelock, 2004; Devedzic, 2004; Mizoguchi *et al.*, 2007).

In practice, to develop an ontology authors use ontology editors that typically offer a graphical interface where it is possible to create/edit ontologies looking deeply on the fundamental concepts, their attributes, properties and relationships, without taking too much attention about how to represent them in a formal language (such as OWL or RDF/RDFS). There are several free ontology editors currently available that can be used for educational purposes, including TM4L (Dicheva and Dichev, 2007), HOZO (Hozo, 2008), OntoEdit (Sure *et al.*, 2002), and Protégé (Protégé, 2008).

In the context of SW and education, ontologies have been applied to solve a va-riety of complex problems, such as knowledge representation in intelligent systems, knowledge sharing and reuse among applica-tions, annotation and search of learning objects, personalization of learning content, be-side many other challenges. A good source of relevant information can be found in the Ontologies for Education - O4E Wiki[2]. Furthermore, notable results in developing and using ontologies to augment web-based learning experiences including both technological and theoretical aspects have been reported in Dicheva and Dichev (2007) and Mizoguchi *et al*. (2007). By technological as-pects we mean the use of ontologies to enable browsing, sharing and reuse of educational content that is possibly located in different repositories allowing the in-teroperability and integration of different

[2] Available at http://o4e.iiscs.wssu.edu/xwiki/bin/view/Blog/.

educational applications. By theoretical aspects we mean the use of ontologies to support the flow of knowledge from theoreticians to authoring practitioners by a comprehensive methodology in which knowledge is created, discovered, shared, and efficiently presented to be used during both authoring of educational content and learning. It is crucial for any intelligent educational application in the era of SW to rely on well-designed and shareable knowledge to support effective learning.

Despite recent advances in the field of SW and ontology engineering, a large-scale use of SW for education is still a futuristic vision rather than a concrete scenario. In this futuristic view we foresee different educational applications (pedagogical agents, educational servers, adaptive learning management systems) communicating with each other exchanging information and mining educational content from the web on behalf of students and teachers. Such content can be integrated with other materials to satisfy various pedagogical needs, teaching styles and/or learning preferences. Moreover, the created content can be shared, adapted and reused for different purposes and for different learners.

There are several difficulties related to the Educational Semantic Web that need to be faced. The automation of ontology development processes, efficient knowledge management, automation of content annotation, integration of Web-services, development of intelligent pedagogical agents, creation of ontologies for instructional design and better techniques for personalization are some of the challenges that need to be overcome. In the next session we will present some research that deals with the challenges.

3.4 An example of application

The range in which SW technologies have been applied to support Web-based education is quite large. There are many applications that already use semantic technologies to bring some advances and benefits for teaching and learning. For instance, we have applications concerned with architectural issues, web-based ITS, pedagogical agents, learning repositories, peer-to-peer applications, etc. Some of such applications were mentioned previously. Other applications include web-based adaptive systems and intelligent earning management systems (Bra *et al.*, 2004; Brusilovsky, 2004). To target our discussion, in this section we focus on one key topic that usually is left behind due to its intrinsic complexity: the development of ontologies for instructional design and its applications for both individual learning and collaborative learning.

The important research issues for the development of intelligent educational systems (IES) include: (i) knowledge modeling, and (ii) extraction of knowledge flows from theory to practice. The latter bridges the gap between theoretical understanding about learning and the practical foundations of design and how to analyze the knowledge of intelligent systems that support the learning process. To support knowledge flows of IES, it is essential to rely on well-designed and shareable knowledge that enables the extraction of domain independent flows. Thus, it is possible to provide pedagogical justification during the creation, selection and delivering of learning contents. Using the ontological engineering approach we can extract the core concepts of learning and instruction from theories (learning theories and instructional design theories) in order to create the basic knowledge that intelligent systems can rely on to offer better advices/recommendations with strong theoretical justifications.

In that direction, we present two research projects that have been done in the Mizoguchi laboratory: one for individual learning (Mizoguchi *et al.*, 2007) and another for collaborative learning (Isotani and Mizoguchi, 2007). Both studies faced the problem that each paradigm or theory has its own definition of learning and instruction. However, as Mizoguchi *et al.* (2007, p. 3) explains: "Every theory has some sort of common basis for explaining learning and instruction, and while the assumed mechanism of developing knowledge is different for each paradigm, the idea of states in the learning process is common". Thus, both works share the idea that there must be an engineering approximation of the states where one can conceptualize learning in terms of state change of learners. From there they develop an ontology based on many theories of learning and instruction. While in individual learning the state change occurs only for learners who receive instruction and the sequences of learning are much more fine-grained size and structured, in collaborative learning (CL) the state change occurs for the ones who receive instruction and the ones who do the action of instruction. In the CL case the state change occurs during the interaction among learners which makes the sequence of learning more complex and less structured than individual learning. The ontology which covers different theories and paradigms about instructional design and learning design for individual learning is open to the public on the web site http://edont.qee.jp/omnibus/.

Besides the development of the ontology itself, another result of these studies was the development of two theory-aware design support systems (SMARTIES for individual learning and CHOCOLATO for collaborative learning). Such systems have the capability of supporting authors with different theories and explain any given advice/recommendation based on a specific theory. As opposed to a conventional expert system in which the theories are implemented as built-in procedures, the theory-

aware systems use ontologies that are completely separated from the code and are understandable from both computers and humans to (a) give a more intelligent and structured support during the design process; and (b) to help the sharing and reuse of knowledge.

We envision that in the future, such ontology will enable different applications to share the same concepts and their meanings. Thus, thinking globally, educational applications can have the same understanding about what is learning and how to be compliant with the existing instructional theories. Furthermore, educational content can be created with strong support of the authoring system that can help to adequately reuse other content and easily annotate new content using concepts form the ontology. Sequences of activities that were designed using some theory can be reused in full or partially for a different purpose by other educational environments, and pedagogical agents can help learners to find content and customize the way how the content is presented according to learners' preferences.

4 The challenges and future directions of the Semantic Web in education

As we discussed already, the Semantic Web has a big potential for improving technology-enhanced learning in many respects. However, the Semantic Web is still in its infancy. Although the corporate SW is already quite popular, the public SW, which is the real Semantic Web is not realistic yet. By corporate SW, we mean the Semantic web used in a corporate (company) and by public SW, we mean the Semantic Web in the WWW setting. The continuous efforts and the current results of the SW community however point that the SW technologies will be incorporated in a large scale on the Web and consequently on web-based learning support systems.

The expectation is that the SW-based educational applications will enable the realization of **AAAL: Anytime, Anywhere, Anybody Learning** using most of the WWW resources as reusable learning objects supported by standard technologies. Such approach is consistent with that of the advancement of the WWW itself, represented by Web 2.0. Such trend facilitates the use of WWW content and resources as knowledge that can be interpreted by computers and learned by people. SW services will provide the essential architecture to make software development much easier than before. People will be able to author their own learning materials helped by SW-enabled learning environments. Appropriate learning resources and services will be easily found by SW-enabled search engines. People would then be able to combine those resources and come up with their own learning materials. Standards-based technology will support interoperability between the resources and created learning materials.

One could ask questions such as "what are the challenges?" or "how soon will the Educational Semantic Web become a reality?" From the authors' point of view, there are still many problems that have to be solved before we reach a large scale level. SW technology needs to advance further with respect to metadata assignment, trust and interoperability between metadata. There are also many problems related to the SW and educational standards, as well as other important SWBES-related problems to be solved.

We could assume that many of the WWW resources are of value to learn. From another hand, learners are also authors of learning content on the Web (e.g., by using blogs, Wikis, and so forth). Then, are the *ad-hoc* learning materials built by laymen valid from the pedagogical point of view? Furthermore, is it possible that social network services on the WWW can help learners to find appropriate learning companions for collaborative learning? If so, in such situations, laymen have knowledge either about how to structure learning materials or about how to collaborate with those companions to maximize their benefits. Besides, no teachers or instructors are available to help them.

Thus, to make such AAAL meaningful and beneficial we need new technologies that make computers more intelligent and provide AAAL learners with such help. From the authors perspective this is the real challenge of SWBES. We believe that one of the technologies that will help AAAL is ontology engineering which is a new generation knowledge technology to help people organize knowledge in a computer-understandable manner. Different research groups have been involved in ontology engineering research in the recent years. Ontology engineering enables us to build the so-called "theory-aware" systems, which can help learners to structure learning materials compliant with instructional/ learning theories and guide them to perform collaborative learning. Such systems have huge potential for making AAAL really meaningful to all learners in the SW era.

5 Final remarks

Semantic Web technologies and applications are getting increasingly popular and adopted in different fields, including education. Research on SW and education has already shown some of the features expected to be embedded in the next generation of learning support systems. Such features include: more adaptive and personalized learning environment; a better use of

pedagogies to enhance instruction/learning; effective information sharing, storage and retrieval; new forms of collaboration with peers; and many other characteristics that enable the realization of AAAL: Anytime, Anywhere, Anybody Learning.

The first steps to the accomplishment of such facts have been taken and we do believe that SWBES will change Education. In fact, to some extent, it has already changed. In the SW era, tools from Web 2.0 for annotation, SW-wikis, collaborative knowledge construction, SW-enabled learning repositories and other applications have been creating new ways for teaching and learning. In this paper we tried to cover some of the main research challenges and possible directions in order to make SWBES pedagogically sound. We focused on the use of ontologies and the creation of "theory-aware" systems, which can help authors to structure and create learning content and effectively guide learners during the learning process.

References

AL-MASRI, E. and MAHMOUD, Q.H. 2007. Discovering the Best Web Service. *In:* INTERNATIONAL WORLD WIDE WEB CONFERENCE (WWW), XVI, Banff, Alberta, Canada, 2007. *Proceedings*... Amsterdam, Elsevier, p. 1257-1258.

ANDERSON, T. and WHITELOCK, D. 2004. The educational semantic web: visioning and practicing the future of education. *Journal of Interactive Media in Education (JIME)*, **7**(1):1-15.

AROYO, L. and DICHEVA, D. 2004. The new challenges for e-learning: The educational semantic web. *Educational Technology and Society*, **7**(4):59-69.

BITTENCOURT, I.I.; DE BARROS COSTA, E.; ALMEIDA, H.O. de; FONSECA, B.; MAIA, G.; CALADO, I. and SILVA, A. P. da. 2007. Towards an ontology-based framework for building mul-tiagent intelligent tutoring systems. *In:* SIMPÓSIO BRASILEIRO DE ENGENHARIA DE SOFTWARE. WORKSHOP ON SOFTWARE ENGINEERING FOR AGENT-ORIENTED SYSTEMS, III, João Pessoa, 2007. *Proceedings*... Porto Alegre, SBC, p. 53-64.

BRAMBILLA, M.; CERI, S.; FACCA, F.M.; CELINO, I.; CERIZZA, D. and VALLE, E.D. 2007. Model-driven design and development of semantic Web services applications. *ACM Transactions on Internet Technology (TOIT)*, **8**(1):3.

BRA, P.; AROYO, L. and CHEPEGIN, V. I. 2004. The Next Big Thing: Adaptive Web-Based Systems. *Journal of Digital Information*, **5**(1). Available at: http://jodi.tamu.edu/Articles/v05/i01/DeBra/. Accessed on 03/15/2008.

BROOKS, C.; GREER, J.; MELIS, E. and ULLRICH, C. 2006. Combining its and e-learning tech-nologies: Opportunities and challenges. *In:* INTERNATIONAL CONFERENCE ON INTELLIGENT TUTORING SYSTEMS (ITS), VIII, Jhongli, Taiwan, 2006. *Lecture Notes in Computer Science,* vol. 4053. Berlin, Springer-Verlag, p. 278-287.

BRUSILOVSKY, P. 2004. KnowledgeTree: A distributed architecture for adaptive e-learning. *In:* INTERNATIONAL WORLD WIDE WEB CONFERENCE, 13, New York, USA, 2004. *Proceedings*... New York, ACM Press, p. 104-113.

CARDOSO, J. 2006. Discovering Semantic Web Services with and Without a Common Ontology Commitment. *In:* IEEE SERVICE COMPUTING WORKSHOP, III, Chicago, Illinois, USA, 2006. *Proceedings*... Los Alamitos, CA, USA, IEEE Computer Society, p. 183-190.

COSTA, E. and BITTENCOURT, I.I. 2007. Developing agent-based AIED systems under the perspective of semantic web. *In:* INTERNATIONAL CONFERENCE ON ARTIFICIAL INTELLIGENCE IN EDUCATION (AIED), XIII, Los Angeles, USA, 2007. *Proceedings*... Amsterdam, IOS Press, p. 726.

DEVEDZIC, V. 2004. Education and the Semantic Web. *International Journal of Artificial Intelligence and Education*, **14**(1):165-191.

DEVEDZIC, V. 2006. *Semantic Web and Education*. 1st ed., Berlin, Springer, 353 p.

DICHEVA, D. and DICHEV, C. 2007. Helping courseware authors to build ontologies: the case of tm4l. *In:* INTERNATIONAL CONFERENCE ON ARTIFICIAL INTELLIGENCE IN EDUCATION (AIED), XIII, Los Angeles, USA, 2007. *Proceedings*... Amsterdam, IOS Press, p. 77-84.

DIETZE, S., GUGLIOTTA, A, and DOMINGUE, J. 2007. Context-adaptive learning designs by using semantic web services. *Journal of Interactive Media in Education (Adaptation and IMS Learning Design)*, **3**. Available at http://jime.open.ac.uk/2007/03/. Accessed on 04/11/2008.

DONG, J. S. 2004. Software modeling techniques and the semantic web. *In:* INTERNATIONAL CONFERENCE ON SOFTWARE ENGINEERING, XXVI, ICSE, Washington, DC, USA, 2004. *Proceedings*... Los Alamitos, CA, USA, IEEE Computer Society, p. 724-725.

GASEVIC, D.; JOVANOVIC, J. and DEVEDZIC, V. 2004. Enhancing learning object content on the semantic web. *In:* IEEE INTERNATIONAL CONFERENCE ON ADVANCED LEARNING TECHNOLOGIES (ICALT), IV, Washington, DC, USA, 2004. *Proceedings*... Los Alamitos,CA, USA, IEEE Computer Society, p. 714-716.

GLINZ, M. and WIERINGA, R.J. 2007. Guest editors' introduction: Stakeholders in re-quirements engineering. *IEEE Software*, **24**(2):18-20.

HENDLER, J. 2001. Agents and the semantic web. *IEEE Intelligent Systems*, **16**(2):30-37.

HOZO. 2008. Hozo ontology editor, Osaka university and Enegate co., ltd. Available at: http://hozo.jp. Accessed on: 01/23/2008.

IEEE. 2008. Learning object metadata. Available at http://ltsc.ieee.org/wg12. Accessed on: 01/23/2008.

IMS. 2008. IMS global learning consortium: Specifications. Available at: http://www.imsglobal.org/specifications.html. Accessed on: 01/23/2008.

ISOTANI, S. and MIZOGUCHI, R. 2007. Deployment of ontologies for an effective design of collaborative learning scenarios. *In:* INTERNATIONAL WORKSHOP ON GROUPWARE (CRIWG), XIII, Bariloche, Argentina, 2007. *Lecture Notes in Computer Science*, vol.4715. Berlin, Springer, p. 223-238.

MILANOVIC, M.; GASEVIC, D.; GUIRCA, A. and DEVEDZIC, G.W.S.L.V. 2007. Model transformations to share rules between swrl and r2ml. *In:* INTERNATIONAL WORKSHOP ON SEMANTIC WEB ENABLED SOFTWARE ENGINEERING, III, Innsbruck, Austria, 2007. *Proceedings*... Berlin, Springer, p. 1-15.

MIZOGUCHI, R. 2004. Tutorial on ontological engineering - part 2: Ontology develop-ment, tools and language. *New Generation Computing*, **22**(1):61-96.

MIZOGUCHI, R.; HAYASHI, Y., and BOURDEAU, J. 2007. Inside theory-aware and standards-compliant authoring system. *In:* INTERNATIONAL WORKSHOP ON ONTOLOGIES AND SEMANTIC WEB FOR E-LEARNING, XIII, Marina del Rey, CA, USA, 2007. *Proceedings*... Los Angeles, AIED, p. 1-18.

MOTTA, E. and SABOU, M. 2006. Next generation semantic web applications. *In:* ASIAN SEMANTIC WEB CONFERENCE, I, Beijing, China, 2006. *Proceedings*... Berlin, Springer, p. 1-6.

PROTÉGÉ. 2008. The protégé ontology editor and knowledge acquisition system. Available at: bhttp://protege.stanford.edu. Accessed on: 01/18/2008.

RDF. 2008. Resource Description Framework (RDF). Available at http://www.w3.org/RDF/ Accessed on: 04/02/2008.

SHAFIQ, M.O.; DING, Y. and FENSEL, D. 2006. Bridging multi agent systems and web services: towards interoperability between software agents and semantic web services. *In:* IEEE INTERNATIONAL ENTERPRISE DISTRIBUTED OBJECT COMPUTING CONFERENCE (EDOC'06), X, Washington, DC, USA, 2006. *Proceedings*... Los Alamistos, IEEE Computer Society, p. 85-96.

SKOS. 2008. Skos core guide, w3c working draft. Available at: http://www.w3.org/TR/2005/WD-swbp-skos-core-guide-20051102/. Accessed on: 01/23/2008.

SURE, Y.; ERDMANN, M.; ANGELE, J.; STAAB, S.; STUDER, R. and WENKE, D. 2002. OntoEdit: Collaborative ontology development for the semantic web. *In:* INTERNATIONAL SEMANTIC WEB CONFERENCE 2002 (ISWC2002), I, Sardinia, Italia, 2002. *Proceedings*... Berlin, Springer-Verlag, p. 221-235.

SWARTOUT, W. and TATE, A. 1999. Ontologies. *IEEE Intelligent Systems*, **14**(1):18-19.

VOUK, M.A.; BITZER, D.L. and KLEVANS, R. L. 1999. Workflow and end-user quality of service issues in web-based education. *IEEE Transactions on Knowledge and Data Engineering*, **11**(4):673-687.

Submitted on January 25, 2008
Accepted on April 11, 2008