The current issue and full text archive of this journal is available at
www.emeraldinsight.com/0969-6474.htm

E-learning agents

Dawn G. Gregg
University of Colorado and Health Sciences Centre, Denver, Colorado, USA

Abstract

Purpose – The purpose of this paper is to illustrate the advantages of using intelligent agents to facilitate the location and customization of appropriate e-learning resources and to foster collaboration in e-learning environments.

Design/methodology/approach – This paper proposes an e-learning environment that can be used to provide customized learning. It utilizes a set of interacting agents that can personalize instruction based on an individual's prior knowledge as well as their cognitive and learning needs. The e-learning agents monitor the e-learning environment and improve learning and collaboration based on learners' prior knowledge, social characteristics and learning style.

Findings – E-learning agents should allow the discovery of new learning objects more easily, allow learners to customize materials presented to improve learning outcomes, and improve collaboration in the e-learning environment.

Originality/value – Little prior research has been done on the use of agents in e-learning environments. This paper proposes a set of e-learning agents that, if implemented in online education or training environments, should provide tangible benefits to organizations.

Keywords E-learning, Intelligent agents, Education, Training, Worldwide web

Paper type Conceptual paper

Introduction

E-learning represents one of the most dramatic changes to impact education and training in the history of education. The internet and multimedia technologies are reshaping the way knowledge is delivered allowing e-learning to emerge as a solution to the problem of lifelong learning and workforce training (Zhang *et al.*, 2004). What makes e-learning content different from other educational materials is that it can be disassembled as individual learning objects, tagged, and stored for reuse in a variety of different learning contexts (Harris, 2005). These learning objects can be assembled into different configurations depending on the requirements of an individual educational situation. This reuse of educational content is one of the core values of e-learning systems (Harris, 2005). While current learning technology can be used to effectively manage the delivery of courses through the web, it does not support learning object reuse (Sicilia and Lytras, 2005).

Research in the areas of intelligent tutoring systems, virtual mentors, and adaptive hypermedia has produced techniques and tools that can provide improved learning outcomes (Brusilovsky, 2000; Melis *et al.*, 2006; Zhang, 2004). However, current systems are either domain specific or non-adaptive and do not support learning object reuse. This has resulted in the search for open intelligent e-learning infrastructures that can be used with standard web technology (Sicilia and Lytras, 2005). Software agents have great potential for addressing the limitations of current e-learning systems by supporting learning processes that target and deliver just-in-time learning materials required by the individual learners. Software agents can be used to support instructors and domain experts with both course design and delivery. They can also support individual learners by personalizing course materials based on learning objectives,

The Learning Organization
Vol. 14 No. 4, 2007
pp. 300-312

0969-6474
DOI 10.1108/09696470710749245

learner characteristics, and prior learner knowledge, and facilitating learner interaction.

Organizational learning environments can include instructor-led synchronous courses, courses developed for asynchronous use, and self-directed learning. The e-learning agent architecture proposed in this paper supports all three of these learning scenarios. The e-learning agent system utilizes "semantic web" metadata descriptions to locate and classify web learning resources (Berners-Lee *et al.*, 2001), planning and scheduling for intelligent course tailoring, personalization techniques to develop an individualized curriculum for each learner, and active monitoring to facilitate collaboration among learners and between instructors and learners.

This paper is organized as follows: the next section reviews related work with learning support systems and autonomous agents. The sections that follow describe the various agents that could be a part of an e-learning agent system and discuss their functionality. The final section summarizes the results, and discusses potential drawbacks of the proposed system and future research directions for agents operating in e-learning domains.

Learning support systems and agents

Learning support systems are designed to support learners and provide improved learning outcomes (Brusilovsky, 2000). Some learning support systems have been proposed for use in traditional e-learning domains. For example, the ActiveMath system is a complex web-based adaptive learning environment with a number of components and interactive learning tools (Melis *et al.*, 2006). Another system designed for higher education courses allows students to conduct searches of external materials (the ACM digital library) from within the learning environment (Gašević and Hatala, 2006). Finally, the Virtual Mentor system is a complete multi-media-based e-learning environment that enables well-structured, synchronized, and interactive virtual instruction. Testing of a prototype Virtual Mentor system indicates that learners that used the Virtual Mentor system had better learning outcomes than learners in traditional classroom settings (Zhang *et al.*, 2004). This research suggests that carefully crafted e-learning systems can benefit learners and provide improved learning outcomes.

Learning support systems have also been implemented in organizational settings. One system that has been successfully implemented is the inter-organizational learning network implemented in the North Carolina wet-processing industry. The system links multiple stakeholders involved in North Carolina's Toxicity Program and successfully allowed them to collaborate and learn from shared publications, trade associations, and consultants (Manring and Moore, 2006). Within three months of beginning the project, significant improvements occurred from suggested process changes and chemical substitutions. Other e-learning systems have been successfully implemented in organizations to perform ongoing sales force training related to new product releases (Chelan, 2006) and to perform skill-based or job-based training (Whitney, 2004). These e-learning systems have demonstrated measurable business results to the organizations in which they were implemented.

One of the problems with existing e-learning systems is that most support only one or two e-learning functions (e.g. material delivery and collaboration). Current systems do not support the development of completely integrated online learning environments

that meet the needs of individual students and groups. Most existing systems require an enormous amount of time on the part of instructional designers to develop instructional videos, presentation slides, lecture notes and other multimedia materials which can then be compiled into an integrated knowledge repository (Zhang *et al.*, 2004). The time commitment required to develop a fully integrated course is not feasible for many e-learning situations because small class sizes make the time commitment impractical, or because the material being taught changes frequently.

This paper proposes that e-learning systems utilize intelligent agents to support instructional design, the retrieval of relevant learning materials, and the processing and analysis of data to enable meaningful e-learning recommendations to be made to instructors and learners. Intelligent agents are programs designed to assist end-users in different ways. Agents can hide the complexity of difficult tasks, perform tasks on the user's behalf, train or teach the user, help users collaborate, or monitor events and procedures (Maes, 1994). Agents operating in heterogeneous networked computing environments are being used as: intelligent search engines (Hsinchun *et al.*, 1998; Lawrence and Giles, 1998; Menczer, 2003; Selberg and Etzioni, 1997; Yang *et al.*, 2000); to track user activities and data to improve end-user decision making (Bui and Lee, 1999, Gandon *et al.*, 2002, Hess *et al.*, 2000); and to find and classify specific types of information on the web (Bui and Lee, 1999; Etzioni, 1997; Gregg and Walczak, 2007). These agents do not attempt to map or understand the entire web. Instead, they attempt to process specific types of content about which the agent has some prior knowledge.

The opportunities for using agents in e-learning applications are enormous. Agent characteristics like autonomy, abilities to perceive, reason and act in specialized domains, as well as their capability to cooperate with other agents makes them ideal for e-learning applications (Papazoglou, 2001). However, many current agents do not provide a comprehensive service to end-users. For example, many previously proposed information retrieval agents are capable of retrieving specific information but do not have the ability to filter, analyze, or make recommendations based on that information (Shaw *et al.*, 2002). Agents are not being used in existing e-learning applications (Woolf and Eliot, 2005). Some researchers have proposed agent-based e-learning systems (e.g. Huang *et al.*, 2006a, b); however, the agent-based systems currently being proposed do not support all aspects of e-learning.

Unlike previous e-learning support systems, the e-learning agents presented in the next sections support instruction design, learning object reuse, personalization and collaboration. They should allow learning objects to be assembled more quickly, while supporting the mass customization of learning materials to meet individual needs.

E-learning agents

Ongoing research into effective learning support systems suggests that in order to support ubiquitous, collaborative, experiential, and contextualized learning in dynamic virtual communities, an e-learning environment should provide the following features for learners: (Allison *et al.*, 2005):

- *Experiential active learning*. Learning resources should be interactive, engaging, and responsive, with active learning and knowledge formation emphasized above simple information transfer.

- *Personalized*. The learning environment should be customized to the individual learners learning styles and educational needs with the quality of the learning experience continually validated and evaluated. This includes customizing accessibility to meet unique learner needs (e.g. to support screen readers, language translation or alternative devices automatically), and dynamically creating appropriate learning contexts.
- *Collaboration socio-constructivist*. Both solitary and group work should be supported.

In addition to the requirements suggested above, e-learning environments can also be used to support learning design, including:

- *Lesson planning*. Agents can be used to perform information gathering and sophisticated reasoning necessary to determine appropriate learning sequences (Woolf and Eliot, 2005; Cassin *et al.*, 2003, Sicilia, 2006).
- *Resource location*. With hundreds of thousands of educational resources available on the web, anyone assembling e-learning materials requires assistance to locate appropriate resources online (Gašević and Hatala, 2006; Woolf and Eliot, 2005). Agents can facilitate location of a wide variety of learning materials, including those that support active learning.

The e-learning environment, shown in Figure 1, includes the agents discussed above. It includes three agents designed to support the learning design process:

(1) an Instruction Agent;

(2) a Lesson Planning Agent; and

(3) a Resource Location Agent.

It also includes a Learner Centered Agent, and a Personalization Agent, to customize the individual learning process. Finally, it includes Collaboration Agents, designed to facilitate and encourage interaction among learners and between instructors and learners. The following sections describe the functionality of these e-learning agents.

Instruction Design Agents

Instruction Design Agents allow the instruction designer to tailor the learning material selection, assist them in identifying appropriate search terms to locate learning materials based on specific concepts, and learning styles, and communicates with the collaboration agents to improve interaction between the instructor and learners in environments with instructor-led learning.

Lesson Planning Agents

One of the most important tasks required when planning a course or training module is the development of the learning design. The learning design includes the assumptions and guidelines used to formulate learning objectives, as well as the selection and scheduling of specific learning activities (Sicilia, 2006). Lesson planning agents can be used to assist with the design of the course structure as well as with the selection of appropriate learning materials. For example, pedagogical agents have been proposed to determine "best-practice" course structures using online catalog descriptions and

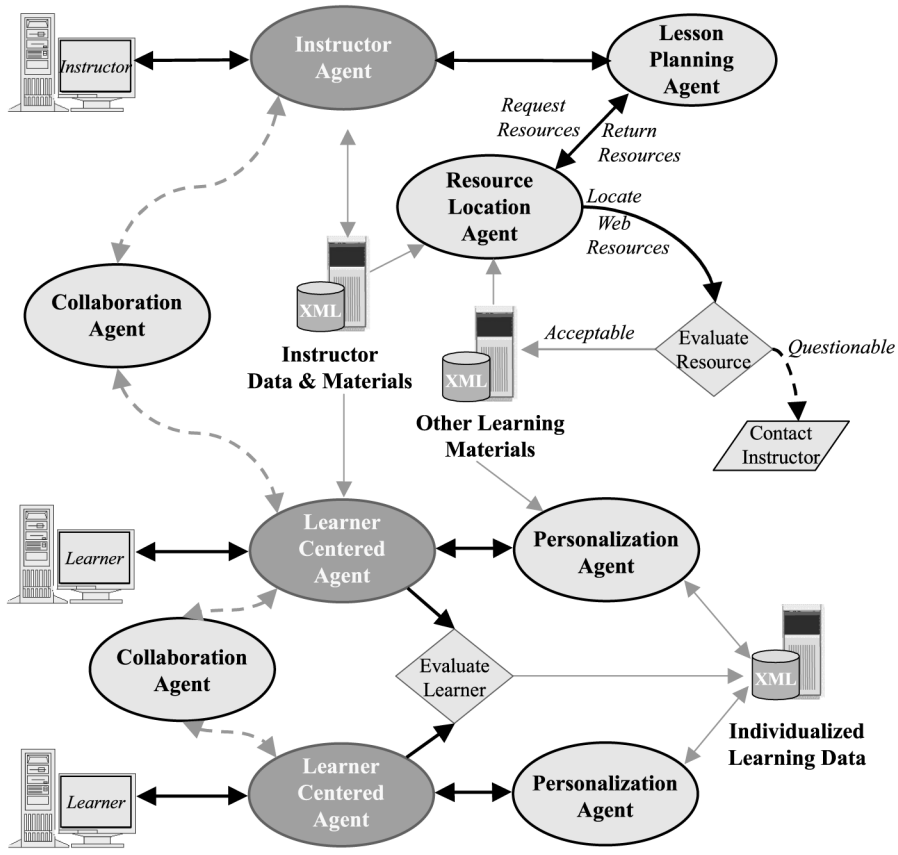

Figure 1.
E-learning agent architecture

syllabi of similar courses (Woolf and Eliot, 2005). These agents assume there is regularity to the order in which subjects are taught (Cassin *et al.*, 2003). The agents select the most frequently occurring topics, then use pair wise frequency to determine which topics appear before or after another most often, and finally propose an appropriate course structure (Woolf and Eliot, 2005).

Once an appropriate course structure is developed, the next step is to dynamically generate recommended instructional resources and schedules, which can be customized for individual learners. This involves both planning and scheduling processes. Planning the course content involves selecting the materials that support a particular educational topic or sub topic. The Lesson Planning Agents retrieve both local and web-based resources and determine if the resources are interactive, engaging, and responsive (to support active learning) and if the resources support a variety of learning styles. If not, the Resource Location Agent can be used to identify additional resources for the specific topic. The materials selected during the planning process then are ordered into a comprehensive linear schedule, based on constraints, such as course timeline and usefulness of materials to prior learners. The Lesson Planning

Agent decomposes complex topics into simpler subtopics to facilitate the ordering of the materials.

The lesson planning process is an iterative one, with the Lesson Planning Agents providing candidate solutions to instruction designers and then allowing them to alter parameters and produce alternate lesson plans. Instruction designers can change the ordering of topics and materials, specify some materials as required, and recommending others for learners that experience difficulties related to a specific topic.

Resource Location Agents

Resource discovery can occur in two modes in e-learning environments. The first occurs when learners explore the digital environment on their own to assemble learning materials based on a self-perceived learning need, and the second occurs when domain experts or instructors assemble the reusable learning objects necessary to support a course or learning module. The web provides access to a huge repository of learning materials; however, anyone wishing to use learning materials available on the web is faced with major challenges. The web is highly dynamic and volatile, with the constant addition of new materials, as well as frequent updating of existing materials and the disappearance or removal of materials (Baeza-Yates and Ribeiro-Neto, 1999). Thus, anyone utilizing web-based learning materials is constantly facing the prospect that important learning resources may be unexpectedly eliminated or the way that they are used may change. In addition, most of the web's content today is designed for humans to read, not for computer programs to manipulate meaningfully. Thus, it is difficult for any computer program to classify new instructional resources correctly as they appear on the web. One answer to this problem is semantic web technologies that can provide the means to describe resources and services, and compose them in virtual learning environments (Berners-Lee *et al.*, 2001).

The purpose of e-learning resource location agents is to locate educational resources available on the web, then evaluate those resources to determine what topics they address, and what learning styles they support. Semantic web technologies provide a semantic infrastructure that enable these agents to accomplish this goal. Providers of learning materials can now deploy resources and services using semantic web metadata that describe the learning content in a uniform way. One of the most widely recognized metadata standards is the IEEE Learning Object Metadata (LOM) (Duval, 2002). It defines relevant characteristics of the learning object including general, life cycle, meta-metadata, educational, technical, educational, rights, relation, annotation, and classification categories.

Resource location and maintenance agents can utilize semantic web metadata to help locate and classify new learning materials as well as to monitor existing resources to determine if they have been changed, moved, or eliminated. These agents are similar to information retrieval agents that have been used in other domains (e.g. Abasolo and Gomez, 2000; Cazalens *et al.*, 2000; Gregg and Walczak, 2007; Rhodes and Maes, 2000; Tan *et al.*, 2002; Walczak, 2003). However, resource location agents need to allow semantic searches of online content to facilitate discovery of appropriate materials based on the conceptual meaning of the subject material (Huang *et al.*, 2006a, b; Shafrir and Etkind, 2006). The main processes that are involved in semantic information retrieval include (Korfbage, 1997):

- a querying process, where the user specifies the types of information to be located using natural language or terms connected by Boolean operators;
- an indexing process, where a document representation is created based on semantic web metadata and word usage; and
- an evaluation process, were a matching between the user query and the document representation is performed using concept parsing algorithms (a generic semantic procedure that identifies the lexical labels and building blocks of concepts) (Shafrir and Etkind, 2006) or ontology mappings (Gašević and Hatala, 2006).

The development of systems utilizing reusable learning objects and the semantic web is in its initial stages; however, there are a few implemented systems that show the promise these technologies hold. For example, the ActiveMath system utilizes the semantic XML for mathematical documents (OMDoc) to create self-describing learning objects that can be selected and linked based on the specific learning contexts. A second semantic web system, Fedora, is designed to allow the storage, management, and dissemination of complex digital objects and the relationships among them (Lagoze *et al.*, 2006). This system is not specifically designed to support learning objects; however, it is designed to support the integration and reuse of digital materials in different contexts, suggesting that domain independent resource location systems are possible using semantic web technologies.

Utilizing an agent based resource location process can help both instructors and individual learners locate and utilize learning resources that facilitate active learning and knowledge formation (e.g. video, Java applets and Flash materials that provide animated demonstrations and/or interactivity). Materials that are deemed appropriate can then be automatically added to lesson plans as needed to support specific learning objectives.

Learner Centered Agents

Learner Centered Agents are responsible for making the learner's interaction with the e-learning environment smooth and effective. They buffer malicious or sub-par performance by resources (e.g. a buggy application) and assemble various educational resources together into as coherent a whole as possible. The Learner Centered agent is responsible for soliciting feedback from learners regarding the effectiveness of specific learning materials; and continuously monitors learning outcomes. It is responsible for communicating with the Personalization Agent and the Collaboration Agent to improve learning.

Personalization Agents

Research on the cognitive information processing model of learning suggests that customizing learning materials based on the individual's preferred learning style or on personality can provide a measurable benefit to the learner (e.g. improved learning outcomes) (Heinström, 2000; Leidner and Jarvenpaa, 1995; Bovy, 1981; Wilson, 2000). Personalization agents can be used to create a personalized learning model and pathway tailored to individual learner knowledge and personality traits (Huang *et al.*, 2006a, b).

Learners begin courses or training sessions by taking knowledge surveys and/or answering questions related to their cognitive, affective, and social characteristics. This allows personalization agents to customize the available learning objects to meet an individual learner's needs. For example, if a learner lacks the prerequisite knowledge for a particular learning objective, additional learning objects can be recommended to correct for the deficit. Personalization agents should be able to select learning materials and optimize schedules for individual learners based on cognitive style, personal preferences, and accessibility needs in addition to prior knowledge and desired knowledge. Personalization agents should accommodate learners with a wide range of skills and backgrounds; allowing learners who are strong in one area to move ahead quickly, while other learners obtain extra assistance.

Personalization agents continuously monitor individual learners progress and use of materials. Learners rate the usefulness of learning materials to them and answer questions that assess their understanding of the subject matter being taught. This information is used to determine the usefulness of materials for teaching specific topics as well as to update the individual lesson plan as the learner interacts with the system.

Collaboration Agents

Collaborative learning has a major role in constructive cognitive development (Piaget, 1928, 1932). Collaboration allows learning to occur in relatively realistic, cognitively motivating, and socially enriched learning contexts. There are a number of experimental studies and implemented systems that emphasize the importance of collaboration to e-learning (e.g. Durfee *et al.*, 1989; Blaye *et al.*, 1990, 1990; Chan and Baskin, 1988; Chan, 1991). Researchers studying e-learning environments have highlighted the need for a variety of collaboration tools including: tools to support socialization between learners and their instructors, community building tools to support the process of building cohesion in a group, and discussion supporting tools (Yli-Luoma and Naeve, 2006).

A collaborative learning system facilitates the refinement and integration of the subject knowledge of learners with the help of the collaborative partners. However, numerous studies show collaboration is more difficult in e-learning environments. These studies cite such components as physical separation, reduced sense of community, disconnectedness, isolation, distraction, and lack of personal attention as contributors to lack of success in various virtual programs (Kerka, 1996; Besser and Donahue, 1996; Twigg, 1997; Stonebraker and Hazeltine, 2004).

Collaboration agents can be used to encourage collaboration between e-learning participants and improve the efficiency of that collaboration. This can include suggesting collaboration where appropriate or taking steps to improve the collaboration. Collaboration agents can monitor the e-learning environment and suggest synchronous "chat" between learners working on similar problems at the same time. They can also point learners to appropriate discussion threads throughout the learning process. These collaboration agents can also identify learners that are having difficulty with a particular topic and facilitate their interaction with the instructor, before they become too lost or spend too much time misunderstanding a particular topic.

One factor that has been demonstrated to influence the efficiency of collaborative learning is the composition of the group (Salomon and Globerson, 1989). If a

collaboration agent observes too much homogeneity among the group members, it can modify some conditions in order to activate collaboration. The agent may allocate roles to participants, which creates conflict or provides them with contradictory information, facilitating collaboration. Collaboration agents facilitate e-learning by increasing the effective interactions between e-learning participants and improving the timing of those interactions.

Evaluation

Research has shown that organizational learning does play an important role in the generation of organizational performance (García-Morales *et al.*, 2006) and that properly managed e-learning programs do provide measurable benefits to organizations, for example Tyco Fire and Security (Whitney, 2004), sales force performance (Chelan, 2006), physicians (Jamieson, 2005), and the textile wet-processing industry (Manring and Moore, 2006). However, most organizations need to be able to measure outcomes so that they can determine the return on investment for their training programs (Whitney, 2004). Thus, an important capability of any organizational e-learning system is the ability to evaluate learning and to provide information that can be used to improve course quality and measure value provided to the company.

The e-learning agent systems proposed in this paper are capable of monitoring individual learning within a course and the usefulness of specific learning objects. Agents can be used to generate learning progress reports against predefined goals and can document learning efficiency as well as learning effort (Huang *et al.*, 2006b). This should allow organizations to manage their e-learning programs to provide the materials and courses that are of the greatest benefit to the organization. The ability to measure the impact of the organization's e-learning program is another important benefit of implementing an agent-based e-learning system.

Conclusions

This article describes a set of interacting e-learning agents that have the capability of assisting instructors with online course design, course scheduling, and learning material location. E-learning agents can also be used to personalize instruction based on learner's prior knowledge (e.g. from knowledge surveys), learning style, and accessibility needs. These agents have the capacity to select and customize resources, problems, and hints. Finally, agents can be used to foster effective collaboration in the e-learning environment.

E-learning agents can be used to provide support to educate instructors and support learning object reuse by helping them locate existing e-learning content. In the dynamic world of the internet, the learning materials available on a particular topic are constantly changing, and hence there is a significant need to continuously monitor existing materials and search for new ones so that the most appropriate course/training materials can be selected. One of the benefits provided by an agent based e-learning system is it can continuously retrieve the most up-to-date educational materials available when creating customized lesson plans for learners. Another advantage of an agent based e-learning system is that it can assist instructors in monitoring learner progress and facilitate interactions between the instructor and

learners that are struggling with a particular topic. They can also be used to optimally place learners in groups formed to solve specific problems.

Introducing agents into the e-learning environment will fundamentally change the way online education is conducted and the outcomes for both learners and instruction designers. As online learners and instructors increase their use of intelligent agents to automate information gathering, lesson planning, learning material customization, and collaboration the outcome for both learners and instructors will be improved. With sufficient information, agents should be able to the select the most appropriate learning materials for individual learners based on both topics covered and learner characteristics, thus improving learning outcomes. Agents can also monitor learning effectiveness so the benefits of the e-learning program can be assessed by the organization.

References

Abasolo, J.M. and Gomez, M. (2000), "MELISA: an ontology-based agent for information retrieval in medicine", paper presented at the ECDL 2000 Workshop on the Semantic Web, available at: http://scholar.google.com/scholar?hl = en&lr = &q = cache:TSbjIzjfkXIJ:www.csee.umbc.edu/~cost/courses/691A_sp03/papers/melisa.pdf + %22information + retrieval + agent%22 (accessed December 2, 2005).

Allison, C., Cerri, S.A., Ritrivato, P., Gaeta, A. and Gaeta, M. (2005), "Services, semantics and standards: elements of a learning grid infrastructure", *Applied Artificial Intelligence*, Vol. 19, pp. 861-79.

Baeza-Yates, R. and Ribeiro-Neto, B. (1999), *Modern Information Retrieval*, Addison-Wesley, Reading, MA.

Berners-Lee, T., Hendler, J. and Lassila, O. (2001), "The semantic web", *Scientific American*, Vol. 284 No. 5, pp. 34-43.

Besser, H. and Donahue, S. (1996), "Introduction and overview: perspectives on … distance independent education", *Journal of American Society for Information Science*, Vol. 47 No. 11, pp. 801-4.

Blaye, A., Light, P., Joiner, R. and Sheldon, S. (1990), "Collaboration as a facilitator of planning and problem solving on a computer-based task", CITE Report 90, Institute of Educational Technology, Open University, Milton Keynes.

Blaye, A., Light, P.H., Joiner, R. and Sheldon, S. (1991), "Joint planning and problem solving on a computer-based task", *British Journal of Developmental Psychology*, Vol. 9, pp. 471-83.

Bovy, R.C. (1981), "Successful instructional methods: a cognitive information processing approach", *ECTJ*, Vol. 29 No. 4, pp. 101-19.

Brusilovsky, P. (2000), "Adaptive hypermedia: from intelligent tutoring systems to web-based education (invited talk)", in Gauthier, G., Frasson, C. and VanLehn, K. (Eds), *Intelligent Tutoring Systems*, Lecture Notes in Computer Science, Vol. 1839, Springer Verlag, Berlin, pp. 1-7.

Bui, T. and Lee, J. (1999), "An agent-based framework for building decision support systems", *Decision Support Systems*, Vol. 25 No. 3, pp. 225-37.

Cassin, P., Eliot, C., Lesser, V., Rawlins, K. and Woolf, B. (2003), "Ontology extraction for educational knowledge bases", in van Elst, L., Dignum, V. and Abecker, A. (Eds), *Agent Mediated Knowledge Management*, Lecture Notes in Artificial Intelligence, Vol. 2926, Springer Verlag, Berlin, pp. 297-309.

Cazalens, S., Desmontils, E., Jacquin, C. and Lamarre, P. (2000), "A web site indexing process for an internet information retrieval agent system", *First International Conference on Web Information Systems Engineering (WISE'00)*, Vol. 1, p. 0254.

Chan, T. (1991), "Integration-kid: a learning companion system", in Mylopoulos, J. and Reiter, R. (Eds), *Proceedings of the 12th International Conference on Artificial Intelligence, Sydney*, Vol. 2, pp. 1094-9.

Chan, T. and Baskin, A. (1988), "Studying with the prince: the computer as learning companion", *Proceedings of the Intelligent Tutoring Systems Conference, Montreal.*

Chelan, D. (2006), "Revving up elearning to drive sales", *EContent*, Vol. 29 No. 2, pp. 28-32.

Durfee, E.H., Lesser, V.R. and Corkill, D.D. (1989), "Cooperative distributed problem solving", in Barr, A., Cohen, P.R. and Feigenbaum, E.A. (Eds), *The Handbook of Artificial Intelligence*, Vol. 4, Addison-Wesley, Reading, MA, pp. 83-148.

Duval, E. (Ed.) (2002), *1484.12.1: IEEE Standard for Learning Object Metadata*, available at: http://ltsc.ieee.org/wg12/files/LOM_1484_12_1_v1_Final_Draft.pdf (accessed June 8, 2006).

Etzioni, O. (1997), "Moving up the information food chain: deploying softbots on the world wide web", *AI Magazine*, Vol. 18 No. 2, pp. 11-18.

Gandon, F., Poggi, A., Rimassa, G. and Turci, P. (2002), "Multi-agent corporate memory management system", *Applied Artificial Intelligence*, Vol. 16 Nos 9/10, pp. 699-720.

García-Morales, V.J., Lopez-Martín, F.J. and Llamas-Sánchez, R. (2006), "Strategic factors and barriers for promoting educational organizational learning", *Teaching & Teacher Education*, Vol. 22 No. 4, pp. 478-502.

Gašević, D. and Hatala, M. (2006), "Ontology mappings to improve learning resource search", *British Journal of Educational Technology*, Vol. 37 No. 3, pp. 375-89.

Gregg, D. and Walczak, S. (2007), "Exploiting the information web", *IEEE Transactions on System, Man and Cybernetics Part C*, Vol. 37 No. 1, pp. 109-25.

Harris, J. (2005), "E-learning strategy: repurposing content", *Chief Learning Officer*, October, pp. 24-8.

Heinström, J. (2000), "The impact of personality and approaches to learning on information behaviour", *Information Research*, Vol. 5 No. 3, available at: http://informationr.net/ir/5-3/paper78.html (accessed June 8, 2006).

Hess, T.J., Rees, L.P. and Rakes, T.R. (2000), "Using autonomous software agents to create next generation decision support systems", *Decision Sciences*, Vol. 31, Winter, pp. 1-31.

Huang, W., Eze, E. and Webster, D. (2006a), "Towards integrating semantics of multi-media resources and processes in e-learning", *Multimedia Systems*, Vol. 11 No. 3, pp. 203-15.

Huang, W., Webster, D., Wood, D. and Ishaya, T. (2006b), "An intelligent semantic e-learning framework using context-aware semantic web technologies", *British Journal of Educational Technology*, Vol. 37 No. 3, pp. 351-73.

Hsinchun, C., Yi-Ming, C., Ramsey, M. and Yang, C. (1998), "An intelligent personal spider for dynamic Internet/Intranet searching", *Decision Support Systems*, Vol. 23, pp. 41-58.

Jamieson, A. (2005), "Ubiquitous computing, the semantic web and the future of e-learning", *Work Based Learning in Primary Care*, Vol. 3 No. 1, pp. 50-7.

Kerka, S. (1996), "Distance learning, the internet, and the world wide web", ERIC Digest, ERIC Document Reproduction Service No. ED 395 214, The Ohio State University, Columbus, OH.

Korfbage, R.R. (1997), *Information Storage and Retrieval*, Wiley, Mississauga.

Lagoze, C., Payette, S., Shin, E. and Wilper, C. (2006), "Fedora: an architecture for complex objects and their relationships", *International Journal on Digital Libraries*, Vol. 6 No. 2, pp. 124-38.

Lawrence, S. and Giles, C. (1998), "Context and page analysis for improved web search", *IEEE Internet Computing*, Vol. 2 No. 4, pp. 36-48.

Leidner, D.E. and Jarvenpaa, S. (1995), "The use of information technology to enhance management school education: a theoretical view", *MIS Quarterly*, Vol. 19 No. 3, pp. 265-91.

Maes, P. (1994), "Agents that reduce work and information overload", *Communications of the ACM*, Vol. 37 No. 7, pp. 31-40.

Manring, S.L. and Moore, S.B. (2006), "Creating and managing a virtual inter-organizational learning network for greener production: a conceptual model and case study", *Journal of Cleaner Production*, Vol. 14 Nos 9-11, pp. 891-9.

Melis, E., Goguadze, G., Homik, M., Libbrecht, P., Ullrich, C. and Winterstein, S. (2006), "Semantic-aware components and services of ActiveMath", *British Journal of Educational Technology*, Vol. 37 No. 3, pp. 405-23.

Menczer, F. (2003), "Complementing search engines with online web analysis agents", *Decision Support Systems*, Vol. 35 No. 2, pp. 195-212.

Papazoglou, M.P. (2001), "Agent-oriented technology in support of e-business", *Communications of the ACM*, Vol. 44 No. 4, pp. 71-7.

Piaget, J. (1928), *Judgement and Reasoning in the Child*, Harcourt Brace, New York, NY.

Piaget, J. (1932), *The Moral Judgement of the Child*, Routledge and Kegan Paul, London.

Rhodes, B.J. and Maes, P. (2000), "Just-in-time information retrieval agents", *IBM Systems Journal*, pp. 685-704.

Salomon, G. and Globerson, T. (1989), "When teams do not function the way they ought to", *International Journal of Educational Research*, Vol. 13 No. 1, pp. 89-100.

Selberg, E. and Etzioni, O. (1997), "The metacrawler architecture for resource aggregation on the web", *IEEE Expert*, Vol. 12 No. 1, pp. 8-14.

Shafrir, U. and Etkind, M. (2006), "E-learning for depth in the semantic web", *British Journal of Educational Technology*, Vol. 37 No. 3, pp. 425-44.

Shaw, N.G., Mian, A. and Yadav, S.B. (2002), "A comprehensive agent-based architecture for intelligent information retrieval in a distributed heterogeneous environment", *Decision Support Systems*, Vol. 32 No. 4, pp. 401-15.

Sicilia, M.A. (2006), "Semantic learning designs: recording assumptions and guidelines", *British Journal of Educational Technology*, Vol. 37 No. 3, pp. 331-50.

Sicilia, M.A. and Lytras, M.D. (2005), "The semantic learning organization", *The Learning Organization*, Vol. 12 No. 5, pp. 402-10.

Stonebraker, P.W. and Hazeltine, J.E. (2004), "Virtual learning effectiveness: an examination of the process", *The Learning Organization*, Vol. 11 No. 3, pp. 209-25.

Tan, B., Foo, S. and Hui, S.C. (2002), "Web information monitoring for competitive intelligence", *Cybernetics & Systems*, Vol. 33 No. 3, pp. 225-51.

Twigg, C.A. (1997), "Is technology a silver bullet?", *Educom Review*, Vol. 31 No. 2, pp. 28-9.

Walczak, S. (2003), "A multiagent architecture for developing medical information retrieval agents", *Journal of Medical Systems*, Vol. 27 No. 5, pp. 479-98.

Whitney, K. (2004), "Jim LaRocco: blazing a path to learning success", *Chief Learning Officer*, available online at: www.clomedia.com/content/templates/clo_cloprofile.asp?articleid = 517&zoneid = 4 (accessed June 8, 2006).

Wilson, E.V. (2000), "Student characteristics and computer-media communication", *Computers & Education*, Vol. 34 No. 2, pp. 67-76.

Woolf, B. and Eliot, C. (2005), "Customizing the instructional grid", *Applied Artificial Intelligence*, Vol. 19, pp. 825-44.

Yang, C.C., Yen, Y. and Chen, H. (2000), "Intelligent internet searching agent based on hybrid simulated annealing", *Decision Support Systems*, Vol. 28 No. 3, pp. 269-77.

Yli-Luoma, P.V.J. and Naeve, A. (2006), "Towards a semantic e-learning theory by using a modeling approach", *British Journal of Educational Technology*, Vol. 37 No. 3, pp. 445-59.

Zhang, D., Zhao, J.L., Zhou, L. and Nunamaker, J.F. (2004), "Can e-learning replace classroom learning?", *Communications of the ACM*, Vol. 47 No. 5, pp. 75-9.

Corresponding author
Dawn G. Gregg can be contacted at: dawn.gregg@cudenver.edu