Socially Intelligent Agent Research at CARTE

W. Lewis Johnson

Center for Advanced Research in Technology for Education (CARTE)
USC / Information Sciences Institute
4676 Admiralty Way
Marina del Rey, CA 90292
johnson@isi.edu
http://www.isi.edu/isd/carte/

Abstract

This paper gives an overview of current research on pedagogical agents at CARTE in the USC / Information Sciences Institute. Pedagogical agents, also nicknamed "guidebots," interact with learners in order to help keep learning activities on track. Social intelligence is required in order to engage in tutorial interactions with the learners, properly interpret the interactions of learners with other agents, and to model characters that can interact with the learners in social settings. At the same time, depth of domain intelligence is typically required in order for the agents to work effectively as advisors or collaborators.

Introduction

The purpose of the Center for Advanced Research in Technology for Education (CARTE) at USC / Information Sciences Institute is to develop new technologies that promote effective learning and increase learner satisfaction. These technologies are intended to result in interactive learning materials that support the learning process, and that complement and enhance existing technologies relevant to learning such as the World Wide Web.

Our work draws significant inspiration from human learning and teaching. We seek to understand and model how people learn from their teachers, from peers, and from their environment, and draw on this knowledge to guide our development of educational technologies. We seek a better understanding of the characteristics that make learning experiences captivating and exciting, and attempt to find ways of fostering these characteristics more broadly and systematically. Our work thus builds upon research in artificial intelligence and cognitive science, and at the same time draws on the experience of specialists in the arts.

A Major Theme: Guidebots

A broad theme of our work has been the creation of "guidebots," or animated virtual guides for learners. We also refer to these guidebots by the more lengthy term of "animated pedagogical agents" (Johnson et al 2000). Guidebots are animated characters that can interact with learners in computer-based interactive learning environments, in order to stimulate and encourage learning. In their complete implementation, they have a number of important features that are relevant to CARTE's goals. They interact naturally with learners, generally in a manner that is inspired by the behavior of human tutors; these interactions include a combination of verbal communication and nonverbal gestures. They express both thoughts and emotions; emotional expression is important in order to portray characteristics of enthusiasm and empathy that are important for human teachers. They are knowledgeable about the subject matter being learned, of pedagogical strategies, and also have knowledge about how to find and obtain relevant knowledge from available resources such as the World Wide Web.

Ultimately, we see guidebots as elements of a variety of rich interactive experiences. In these experiences, students have significant freedom to explore learning materials and perform activities that reinforce their learning, either individually or in groups. The guidebots serve a number of important functions in these environments.

- **They help keep the learning on track.** People have a tremendous capacity to learn, but they fail to utilize this capacity effectively if they fail to take advantage of the resources available to them, or if they fail to apply the right metacognitive skills. Guidebots can remind learners of available resources, and can reinforce good learning habits. They can offer help and guidance when the students get stuck, and provide feedback to the learners on their progress.
- **They provide an additional communication channel.** Guidebots are a user interface component, and play important roles within an overall educational user interface design. They are extremely effective at directing the learner's attention to what is important in the learning environment. As learners view instructional materials, guidebots can provide useful commentary on those materials. They can also provide learners with help in navigating complex learning environments. They provide both highly salient and

highly nuanced interaction. Human personae have much greater expressive capabilities than conventional user interface elements, and people are well practiced in reading these expressions.

- **They act as the teacher's representatives.** They are able to interact with the learners at times when a human teacher is not available. At the same time, they collect data about their interactions with the learners that can be valuable to teachers in assessing the learners' skills and planning future computer-based learning experiences.

Guidebots play one role within the overall envisioned environment described here. There are other important roles that must be supported.

- **Supporting Characters.** Many learning experiences include additional characters, such as synthetic team members or inhabitants of virtual worlds. These do not act as the learner's guide, but they nevertheless support the learning objectives of the experience through their interactions with the learners.
- **The Director.** Borrowing the dramatic metaphor, it is important to have a director who can guide the overall action. In some applications a human is in the loop to help direct the action, and in other applications we want the direction to be performed automatically. The director needs to assess whether the current interaction or "scene" has achieved its intended instructional function, and when it is time to move to another scene. The director may influence the way the guidebots and supporting characters interact with the learners, depending upon how the action unfolds. If the director determines that the current learning objectives have been met, it may guide the interaction toward situations that address new learning objectives. The director thus requires real-time planning and assessment capabilities. In some applications the director also needs to control the visual presentation of the scene, thus serving as **cinematographer**.
- **The Author.** Guidebot technology will become practical only if it becomes easy to design and create the interactive experiences that incorporate guidebots. New kinds of authoring tools are needed that support the unique characteristics of guidebot-enhanced learning experiences, and that take advantage of the learning materials that are available on the World Wide Web, in digital libraries, and elsewhere.

Guidebots can be integrated into a variety of interactive media, and the resulting interactive experiences can be delivered in different ways. The following are the media that are of interest to CARTE. They currently require distinct technologies; however technology advances are blurring the distinctions between them.

- **Virtual environments**. The action takes place within a virtual world. Learners can manipulate objects in the virtual world, and through their manipulations can practice performing tasks. Each learner has a presence in the virtual world, in the sense that guidebots and other participants can observe them and interact with them. 3D worlds such as Steve's immersive mockups are prime examples. However, 2D interactive simulations used by Web-based guidebots can also serve as virtual environments, insofar as the guidebot can observe the learner's manipulation of objects on the screen and react to them.
- **Web-based information spaces**. The World Wide Web is a common medium of instruction, and therefore we design guidebots to operate in conjunction with this medium. In general the Web does not support a strong spatial geometry, nor do the learners have a spatial location within it. 3D spaces can be found on the Web, but they constitute a small fraction of Web sites at this time. In order to assist Web-based learning, guidebots receive notifications when learners view pages and click on links on the pages, and may respond to those actions.
- **Interactive pedagogical dramas**. The software presents a dramatic story, using sound and images. Learners can influence what takes place in the drama, and the characters can adapt their behavior in response. If the drama is presented in a virtual environment, then the learners can play roles within the story themselves. However, added flexibility can be attained if there is some separation between the learner and the action, i.e., where the computer screen frames the action. The learner then shares duties with the automated director in guiding the action. This structure creates opportunities to present back-story material as needed, and to control the learner's view via cinematographic techniques. In such scenarios the guidebot typically acts as buddy or advisor to the character or characters that are being directed by the learner.

Finally, guidebots can serve useful instructional roles in environments whose purpose is not primarily instructional. For example, guidebots can be embedded in software packages to provide just-in-time training, and in interactive games to teach users how to play. Whenever users have particular tasks to perform or problems to solve, guidebots can potentially provide assistance.

A number of CARTE projects are conducted in collaboration with other research groups, in computer science and in educational application areas. We are working with USC's new Institute for Creative Technologies to develop more engaging immersive training experiences. Other collaborators include health science research centers and teaching faculty at USC and elsewhere. These collaborations are essential both for identifying the deficiencies in current teaching practice that guidebots can address and assisting in the evaluation of guidebot applications in instructional settings.

Example Guidebots

CARTE has developed a number of animated pedagogical agents that have served as vehicles for developing and testing key aspects of the underlying technologies. Papers describing these projects are listed in the references and available on the Web at http://www.isi.edu/isd/carte.

Steve

Steve (Soar Training Expert for Virtual Environments) assists procedural skill training in immersive virtual environments, such as virtual mockups of engine rooms (Rickel and Johnson 1999a). Steve supports both individual and team training; he can advise learners as they perform roles within teams, and he can play the role of a missing team member (Rickel and Johnson 1999b). Steve operates within a networked virtual environment, interoperating with a collection of other components including the Vista Viewer visualization system of Lockheed Martin and the VIVIDS simulation authoring tool (Johnson et al. 1998).

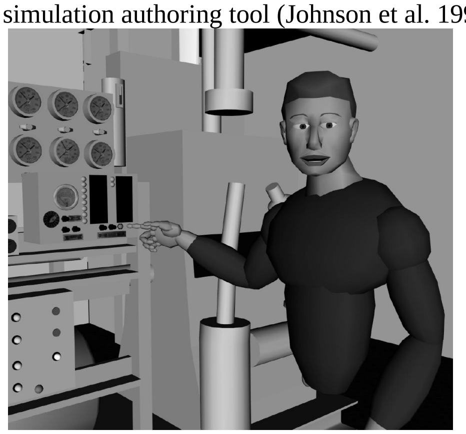

Figure 1. Steve pointing at an indicator light

Steve uses the Soar cognitive architecture (Laird et al. 1987) to model adaptive task execution in dynamic environments. Like other intelligent tutoring systems, he can monitor students' actions, point out errors, and answer questions such as "What should I do next?" and "Why?" However, because he has an animated body, and cohabits the virtual world with students, he can provide more human-like assistance than previous automated tutors could (Rickel & Johnson 2000). For example, he can demonstrate actions, use gaze and gestures to direct the student's attention, and guide the student around the virtual world. When playing the role of a student's teammate, Steve's human body allows students to track his activities as they would track those of a human teammate. Finally, Steve's agent architecture allows him to robustly handle a dynamic virtual world, potentially populated with people and other agents; he continually monitors the state of the virtual world, always maintaining a plan for completing his current task, and revising the plan to handle unexpected events.

In addition to Steve's novel instructional capabilities, he was designed to simplify the development of new training applications. Unlike many computer-aided instruction programs, Steve's instructional interaction with students need not be scripted. Instead, Steve includes a variety of domain-independent capabilities for interacting with students, such as explanation generation and student monitoring. Steve can immediately provide instruction in a new domain given only simple knowledge of the virtual world and a description of the procedural tasks in that domain. This approach results in more robust interactions with students than course designers could easily anticipate in scripts.

Web-Based Guidebots

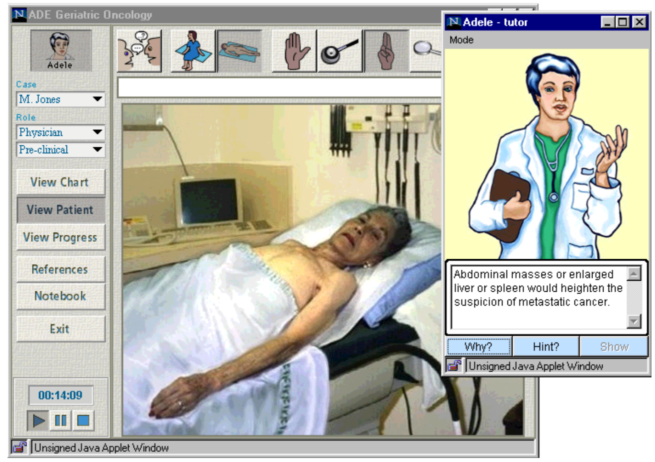

Figure 2. Adele guiding a student through a clinical case

A number of guidebots for Web-based instruction have been developed. They rely upon a common distributed architecture and share component modules, which facilitates the creation of new guidebot applications. All focus on helping students acquire particular types of problem solving skills, such as planning or diagnostic reasoning. Students work through interactive exercises, receiving guidance, feedback, and evaluation from the guidebot as needed. Guided exercises are typically combined with other kinds of Web-based learning materials to create on-line courses.

Adele (Agent for Distributed Learning Environments) supports on-line case-based problem solving, particularly in the health sciences (Shaw et al 1999). Adele monitors the student as he or she works through a simulated case, downloaded to the student's client computer. As the student proceeds Adele compares the student's actions against a model of how the task ought to be performed. The task model is in the form of a set of hierarchical partial order plans, with different plans applying to different situations. Adele may give hints, explain the rationale for recommended actions, point the learner to relevant on-line references, and intervene if the student is making serious mistakes. The amount of intervention can be changed depending upon the instructional objectives of the module and the needs of the student. During the interaction Adele currently responds to the learner using a combination of verbal and nonverbal gestures. The Adele architecture supports alternative student monitoring engines for different types of problem solving, and an alternative engine has been developed to help students with diagnostic reasoning tasks (Ganeshan et al. 2000).

PAT (Pedagogical Agent for Training) is an implementation of Steve's procedural skill training representation compatible with the Adele architecture. PAT incorporates a model of tutorial dialog, enabling it to place its interactions with the learner in the context of a coherent dialog.

ALI (Automated Laboratory Instructor) applies the guidebot approach to on-line science experiments. ALI monitors students as they conduct experiments on simulated physical systems. As the student manipulates simulation variables, ALI interprets the simulation results using a qualitative model of the system, defined using Qualitative Process Theory. ALI can then quiz the student to see whether he or she interpreted the simulation results in the same manner. ALI can also critique the student's experimental technique, to make sure that they are experimenting with the system thoroughly and systematically.

Gina and Carmen

Figure 3. Carmen in Gina's office

CARTE is also integrating guidebots into interactive pedagogical dramas. An example of an application using this approach is *Carmen's Bright IDEAS*, an interactive multimedia training course designed to help mothers of pediatric cancer patients develop problem solving skills (Marsella et al. 2000). Learners are presented with a multimedia dramatic story about a mother, Carmen, who faces a variety of problems at home and at work relating to her daughter's illness. Gina, a clinical trainer, helps Carmen to learn how better to address her problems and try to solve them. In each run through the story, the user can direct the thoughts and moods of either Carmen or Gina, who then behaves in a manner consistent with those thoughts and moods. The character that the user is not controlling acts autonomously in response to the other character. The unfolding of the story line thus is different for each run through the story.

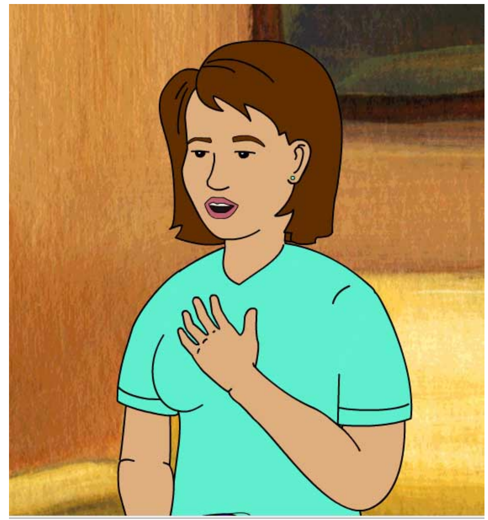

Figure 4. Carmen talking about her problems

Current Research

The following are some guidebot-related research topics that CARTE is currently investigating.

Figure 5. Improved human figure model for Steve

- **Increasing realism of appearance and behavior.** Currently our guidebots have a distinctly stylized and artificial appearance. In some applications such as *Carmen's Bright IDEAS* this is a deliberate stylistic choice, which can be appropriate when realism is not necessary to help the guidebots achieve the intended instructional objectives. However in immersive environments such as the engine room that Steve inhabits in Figure 1, a realistic appearance is important both to increase believability and to give the guidebot a greater ability to demonstrate skills. We are currently working with USC's new Institute for Creative Technologies in order to improve a new version of Steve with highly realistic appearance and behavior. Steve's agent "brain" will be used to control a realistic human figure, developed by Boston Dynamics, coupled with a realistic face model developed by Haptek, Inc. The new Steve will be able to model complex behaviors and exhibit believable facial expressions. This will enable Steve to be employed in new types of training applications, including those where social interaction skills are crucial.

- **Speech communication.** A number of our guidebots employ text to speech synthesis (TTS) in order to communicate with learners. Steve furthermore supports speech recognition. TTS affords flexibility for interactive learning applications since the guidebot can generate utterances dynamically and is not limited to particular utterances that were recorded beforehand. Unfortunately, limitations in TTS technology limit its usefulness; guidebot voices can sound monotonous and artificial, and can be difficult to understand at times. We are investigating ways of making more effective use of speech processing technology. We are developing models of how to employ prosody effectively in instructional interactions. This involves observing interactions between human teachers and students, and recording professional actors as they deliver lines appropriate for instructional interaction. We then are modeling the prosody contours using available TTS packages.
- **Synthetic face-to-face interaction.** Steve and Adele both have the ability to engage in face-to-face communication with learners, combining speech and gesture. Face-to-face communication provides them with both direct and subtle means to communicate with learners and provide them with feedback. Gaze, head position, and body position can be used to indicate the guidebots' focus of attention, and to indicate when they are communicating and to whom. They help make these guidebots appear more aware of their environment, and hence more believable as intelligent guides. We are now interested in improving the naturalness of our guidebots' face-to-face interaction, using nonverbal gestures to support and regulate face-to-face communication. We also see potential for using body language to depict the mental state of supporting characters and encourage empathy on the part of the learner. This use of body language is exhibited to some extent by Carmen, as illustrated in Figure 4, and is something that we continue to investigate. Meanwhile we continue to develop models of tutorial dialog that can be incorporated into such face-to-face interaction (Rickel et al 2000).
- **Student monitoring.** All of our work hinges on our agents being able to perform plan recognition in a general sense, to be able to understand what strategies students are following as they solve problems. Our hypothesis is that students can be effectively monitored across a range of applications using a small number of domain-independent monitoring engines focused on particular skills, such as diagnostic problem solving or experimentation. We continue to develop and test this hypothesis. For example, we are currently working with science faculty at California State University at Los Angeles to determine whether the ALI experimentation model can be applied to new types of science experiments. In the process we are testing the limits of Qualitative Process Theory as a method for modeling physical systems, and identifying new types of problem solving skills that are relevant to experimental science.
- **Team performance analysis.** The area of team training is important, and not well supported by intelligent tutoring systems. We have developed two systems that exhibit important technologies for team performance analysis. One is the PROBES system, which monitors the performance of tank platoons in a simulated armor training exercise (Marsella & Johnson 1998). The other is ISAAC, which analyzes team performance and identifies factors that contribute to team success or failure (Raines et al 2000). Both have a role to play in the team analysis capabilities that we envision. PROBES is effective where a well defined model of team behavior and team performance objectives exists; this is encoded in the situation space model that PROBES uses to track the learner. ISAAC is more appropriate when such a model is lacking, as it helps to acquire a model from team performance data. We are interested in integrating and developing these team analysis capabilities, and applying them in team training exercises utilizing the new realistic version of Steve.
- **Models of emotion.** People naturally read emotions into animated characters. Furthermore, emotional response is an essential aspect of face-to-face tutorial interaction. We must therefore design our guidebots so that they impress the learner as having the right emotional responses at the right time. We therefore have been developing dynamic models of emotion, and testing various combinations of facial expression and body language in order to determine how best to convey emotion to learners.
- **Models of personality and character.** Models of emotion of are important for believable characters in guidebot-enhanced learning applications, but they are not sufficient, particularly in interactive pedagogical dramas. Pedagogical dramas require characters with personalities, which help to determine how characters tend to react cognitively and emotionally to different situations. Personality characteristics also can influence how characters express their emotions. We also require models of character development, so that the characters' personality attributes can change in appropriate ways over time. We are investigating these issues in the context of a new pedagogical drama project called IMPACT, intended to foster good eating and exercise habits in 4th and 5th graders. The IMPACT game has several main characters, each of which has

different personality characteristics that change over time.

- **Automated direction.** *Carmen's Bright IDEAS* supports nonlinear story interaction, by determining what takes place within a scene and when scene transitions take place. It also provides automated cinematography, character direction, and shared directorial control. We are now generalizing these mechanisms so that they can be applied to a range of interactive pedagogical dramas.
- **Authoring technology.** Current authoring tool research is exemplified by Diligent, a system developed by Richard Angros that learns procedures from a combination of observing expert demonstrations and performing experiments (Angros 2000). Diligent demonstrates that interactive authoring tools can effectively exploit machine learning techniques. Advanced authoring techniques such as these are important in order to ensure the broad applicability of guidebot technology; conventional authoring tools designed for scripted instruction is not appropriate for guidebot design. We are engaged in a number of authoring research and development activities. Andrew Scholer is building upon Angros's model to support authoring via interactive tutorial dialog – tutoring the agent so that the agent can then tutor students (Scholer et al. 2000a & b). A graphical interface to Adele's plan representation has been developed so that domain specialists can modify Adele's task knowledge. Finally, we are developing methods for reusing elements of Adele's cases, so that new case-based exercises can be constructed rapidly.

Acknowledgments

CARTE includes the following faculty and staff members: Jeff Rickel, Stacy Marsella, Richard Whitney, Erin Shaw, Kate LaBore, Erin Shaw, Frederica Stassi, and Marcus Thiebaux, and Fanny Mak. Students and interns include Rogelio Adobbati, Shish Aikat, Paul Cho, Teresa Dey, Aaron D'Souza, Daniel Mellet D'Huart, Carlos Fernandez, Stephen Kim, Girish Narayanan, Brett Rutland, Narayanan Sadagopan, Girish Srinivasan, and Daisy Zhang.

The work described in this paper was conducted with support from the Office of Naval Research, Air Force Research Laboratory, US Army STRICOM, National Cancer Institute, US Department of Agriculture, National Institute of Child Health and Human Development, the National Science Foundation, and internal grants from the University of Southern California and USC / Information Sciences Institute.

References

Angros, R. (2000). *An Agent that Learns to Instruct: Exploiting Demonstrations through Experimentation.* Ph.D. Thesis, University of Southern California.

Ganeshan, R., Johnson, W.L., Shaw, E., & Wood, B. (2000). Tutoring diagnostic problem solving. *Proceedings of ITS 2000*, Springer-Verlag, Berlin.

Johnson, W.L., Rickel, J.W., & Lester, J.C. (2000). Animated Pedagogical Agents: Face-to-Face Interaction in Interactive Learning Environments. To appear in *International Journal of Artificial Intelligence in Education* 11, 47-78.

Johnson, W.L., Rickel, J., Stiles, R. and Munro, A. (1998). Integrating pedagogical agents into virtual environments. *Presence: Teleoperators and Virtual Environments*, 7(6):523—546.

Laird, J.E., Newell, A., and Rosenbloom, P. (1987). Soar: An architecture for general intelligence. *Artificial Intelligence* 33:1-64.

Marsella, S., & Johnson, W.L. (2000). An intelligent assistant for team training in dynamic multi-agent virtual worlds. In Proceedings of ITS '98, 464-473, Springer-Verlag, Berlin.

Marsella, S., Johnson, W.L., and LaBore, C. (2000). Interactive Pedagogical Drama. In *Proc of the 4th Intl. Conf. on Autonomous Agents*, Barcelona, Spain. ACM Press, New York.

Raines, T., Tambe, M., & Marsella, S. (2000). Automated assistants to aid humans in understanding team behaviors. Proceedings of Agents 2000, 419-426, ACM Press.

Rickel, J., Ganeshan, R., Rich, C., Sidner, C.L., & Lesh, N. (2000). Task-oriented tutorial dialogue: Issues and agents. Working Notes of the AAAI Fall Symposium on Building Dialogue Systems for Tutorial Applications, November 2000.

Rickel, J., and Johnson, W. L. (1999a). Animated agents for procedural training in virtual reality: Perception, cognition, and motor control. *Applied Artificial Intelligence* 13:343-382.

Rickel, J. and Johnson, W.L. (1999b). Virtual humans for team training in virtual reality. In *Proceedings of the Ninth World Conference on Artificial Intelligence in Education*, pages 578-585. IOS Press, 1999.

Rickel, J. and Johnson, W.L. (2000). Task-oriented collaboration with embodied agents in virtual worlds. In *J. Cassell, J. Sullivan, S. Prevost, and E.Churchill* (Eds.), Embodied Conversational Agents, MIT Press.

Scholer, A., Rickel, J., Angros, R. Jr., & Johnson, W.L. (2000a). Acquiring and using task knowledge for training in virtual reality. IUI-2000 Workshop on Using Plans in Intelligent User Interfaces.

Scholer, A., Angros, R. Jr., Rickel, J., and Johnson, W.L. (2000b). Teaching animated agents in virtual worlds. *In Working Notes of AAAI Spring Symposium on Smart Graphics*.

Shaw, E.; Johnson, W. L.; and Ganeshan, R. (1999). Pedagogical agents on the web. In *Proceedings of the Third International Conference on Autonomous Agents*, 283-290. ACM Press, New York.