The Many Roles of Virtual Agents in Training

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ABSTRACT

The simulation and training community has long recognized the value of virtual agents in simulations. Virtual agents have been used to populate simulations and war games to represent characters in the virtual world who interact with a player to drive a simulation forward. The technology to imbue these agents with realistic behavior is becoming increasingly sophisticated.

The role of virtual agents in training, however, should not be limited to providing realistic characters in a virtual world. These agents can be exploited in other powerful ways to assist in training. For example, virtual agents can be used to provide coaching and feedback to a trainee. Getting feedback from the environment and/or an instructor is an important factor determining training effectiveness. Virtual agents, such as virtual team mates, can provide feedback on the correctness of a trainee’s actions in a simulator and also provide coaching on occasions. This simulates the real-world condition where people receive feedback and coaching from their team mates on a job.

Virtual agents can also provide training assistance by adapting their behavior to the trainee’s actions. For example, when a simulation provides virtual team mates, the expertise level of the team mates can be adjusted to the trainee’s expertise level. A novice learner can be matched with expert team mates and more advanced students can be matched with less experienced team mates to help him practice team work skills.

Finally, virtual agents can also provide trainees with opportunities to learn through teaching. Thus, simulations can include virtual apprentices who have to be taught certain skills by the trainee. Studies have shown that the act of teaching someone else leads to deep levels of learning.

ABOUT THE AUTHORS

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VIRTUAL AGENTS: WHAT ARE THEY?

There is no single clear definition of agents and how they differ from programs (Franklin and Graesser, 1996). Of the several definitions they offer, the following seems the most appropriate for the current discussion:

Intelligent agents continuously perform three functions: perception of dynamic conditions in the environment; action to affect conditions in the environment; and reasoning to interpret perceptions, solve problems, draw inferences, and determine actions (Hayes-Roth, 1995).

Virtual intelligent agents are gaining currency in several different types of applications. Here we will focus on their use in training applications. Agents can be used to represent sentient and non-sentient entities. For example, a simulated aircraft is as much of a virtual agent as simulated enemy combatant. However, we are more interested in agents that represent human-like sentient beings and project human-like attributes.

Virtual agents are most common in simulations. The role and importance of virtual agents in simulations is obvious. They make simulations dynamic and help evolve them in interesting and unexpected (from the trainee's perspective) ways. Such agents, commonly referred to as Non-Playing Characters or NPCs, are also found in most 3-D games. Typically, however, these agents do not take on any pedagogical role other than enabling the participation of the student in a realistic simulation of the tasks for which they are being trained. The following sections describe some other roles for virtual agents in training applications that ascribe to them some pedagogical capabilities.

VIRTUAL AGENTS IN SIMULATIONS

Dynamic behavior is an important characteristic of a virtual simulation. In the context of training, virtual simulations are not only dynamic, but also interactive. Agents can vary in the range of behavior complexities they exhibit. Agent behaviors can range from simple scripted actions to intelligent, complex decision making capabilities in response to simulation context. The behavior of autonomous agents is typically governed by rules or scripts.

Consider the simulation-based Intelligent Tutoring System for training Tactical Action Officers being used at the Surface Warfare Officers School (SWOS) (Stottler and Vinkavich, 2000). The simulator used in this tutor has a realistic reproduction of the environment in which a TAO operates. Very briefly, a tactical action officer is located in a warship such as the Aegis Cruiser, and his task is to make tactical decisions based on current situation assessment which consists of knowing what threats are presented by enemy aircraft and ships, and knowing the availability and position of his own defensive and offensive assets. The scenarios presented by this tutor place the trainee in the role of a TAO who has to monitor threats and take appropriate actions while staying within the rules of engagement. The threats, in the form of enemy aircraft and patrol boats, are all virtual agents with autonomous behaviors. Some of these agents exhibit simple behaviors as shown in Figure 1. This shows a flowchart where the rectangles represent states and ellipses representing conditions. This represents the behavior associated with commercial planes following a path. The flowchart directs the agents (in this case commercial planes) to follow the lane and terminate when the end of the lane is reached.
A more complex behavior is shown in Figure 2 and is associated with an enemy patrol boat. An agent following this behavior will actively look for an enemy platform, follow it and fire upon it when it gets within range. However, should the platform being pursued flash a warning signal, the agent will flee. Using scripts such as the ones shown, or using rules, it is possible to create agents which exhibit a great degree of intelligence.

Thus, agents make it possible to present a realistic scenario that tests the trainee in real-time situation assessment and decision-making skills.

AGENTS AND TEAM TRAINING

One specialized use of virtual agents in simulations is to play the role of absent team members in a team training application. Team training is becoming increasingly important as organizations realize that reasons for sub-optimal performance can be traced to...
gaps in team performance skills rather than individual skills. Team training faces all the training issues faced by individual training: it is expensive to schedule and conduct, and customized one-on-one training that is highly effective is infeasible due to its high cost. In addition, it is difficult for one facilitator to follow the actions of each individual team member to assess their performance and its effect on the overall team performance. Simulation-based training ameliorates these problems by facilitating distance learning and by doing away with the resource requirements and costs associated with live training. Furthermore, the actions of each individual can be automatically logged for later analysis, giving the facilitator the omniscience so lacking in live training exercises. For these reasons, the role of virtual simulations in team training is gaining in significance. These benefits can be extended through the use of virtual agents to play the role of other team members. Why would it make sense to train an individual with virtual teammates instead of real people? The benefits are as follows.

1. Training can be customized to an individual while simultaneously enabling the learning of team-oriented performance. Virtual agents can adapt their behavior to suit the situation. For example, agents can exhibit decreased levels of expertise as a trainee’s expertise level increases so that the trainee’s team performance skills such as helping teammates, compensating, communicating effectively, etc. can be practiced and assessed. Thus, simulation-based training with virtual agents playing the role of other team members enables training scenarios to be engineered to a particular trainee’s needs in ways that are infeasible with real people.

2. This setup allows an individual to undergo remedial training in order to catch up with the rest of the team without wasting others time. It is often difficult to put together teams of people with similar expertise levels. When teams of people with widely disparate skill levels train together, either the more advanced members are left feeling bored, or the more novice members are left feeling challenged beyond capacity. Either situation leads to a frustrating and ineffective learning experience. A training environment with virtual agents playing the role of team member brings in an element of self-paced learning to the area of team training.

3. Simulation-based Intelligent Tutoring Systems (ITS) are gaining increasing currency within the military. ITSs are systems that automatically assess a student’s strengths and weaknesses through evaluations of their performance and deliver training that is highly responsive to a trainee’s needs. ITSs have shown to be effective in achieving learning outcomes close to those achieved via human one-on-one tutoring. The tutoring component of an ITS is typically modeled as an omniscient observer that knows everything leading to a great power imbalance between the tutor and the tutee. A subtler way of achieving the same benefits would be to channel some feedback, coaching, and other instructional interventions through the environment itself. This is enabled by the use of virtual agents in team simulations. These virtual agents can support the ITS in assessing the student’s performance, and providing coaching and feedback. This is illustrated in the example discussed below.

We have developed a prototype hyperbaric tutoring system that illustrates some of these ideas (Ramachandran et. al., 2003). This is a simulation-based tutor for teams of hyperbaric treatment providers. The prototype includes a simulation of the chamber controls and an interface for team communication. The simulation is designed to train a chamber operator in emergency procedures. A hyperbaric treatment team for a multi-place chamber typically includes a chamber operator who operates the chamber, a crew chief for team co-ordination, a medical officer who makes medical decisions, and an inside observer who monitors the patient inside the chamber. The prototype trainer models all the other members of the team (besides the chamber operator who is the person being trained) as virtual agents who interact with the trainee through text messages sent to the simulator interface.

In addition to serving as proxies for missing team members, the virtual agents serve important pedagogical roles in this prototype. First and foremost, they provide the trainee with feedback and coaching. One of the training scenarios was designed to teach a chamber operator the basics of ascent (also called climb) and descent (often called a dive) procedures. Often during a dive, a patient will experience barotraumas or ear pain due to increased pressure. This symptom is typically relieved by climbing a couple of feet and waiting for the patient to adjust to the pressure before resuming the dive. This procedure is commonly referred to as a “bounce”. The following figures show a series of screen captures illustrating how the virtual agents provide tutoring support. Notice that in Figure
3, the virtual medical officer informs the trainee that the chamber is descending too fast. This is closer to reality as in real life, a chamber operator will receive feedback from a teammate or the environment rather than an omniscient tutor. Figure 4 shows the medical officer requesting a bounce in response to notification that the patient is experiencing barotrauma. Figure 5 shows the medical officer explaining how to execute a bounce (ascend the chamber by 2 feet) when the chamber operator fails to act in a timely manner. Thus, the virtual medical officer offers feedback and coaching as the need arises.

A second feature of the prototype is the ability of the virtual teammates to adapt their behavior to the trainee’s expertise level. The examples shown in Figures 3 through 5 are for a novice trainee. In this phase of a trainee’s learning experience, the virtual agents exhibit a high degree of expertise; the justification for this being that a novice trainee needs to focus on learning the basic skills and won’t necessarily be equipped to handle erroneous feedback. However, as the trainee advances, the virtual team mates can start making mistakes, and it would be the trainee’s responsibility to judge the correctness of this feedback and act accordingly.

This example illustrates the possible roles of agents in team training applications.
Getting Started

This panel is your tutor panel and it where you will have interactions the tutor, as well as where the tutor will provide you with help and hints as you progress through the simulation. If at any point during your simulated scenario, you find that you need help, look here and the tutor will provide you with direction.

The panel on your right is the simulation panel. This is where you will find your valve controls, pressure gauges, communication channel, and all other simulated controls. Actions you perform in this panel will affect your final evaluation and may only be done while the simulation is running.

On the right panel, the four buttons at the bottom are the simulation controls. These allow you to start, stop, pause

Figure 4: Instructions given to the student by a virtual agent
AGENTS AS LEARNING COMPANIONS

While virtual team mates provide tutoring assistance to a trainee, they are not collaborators in the learning experience. Many learners enjoy having learning companions with whom they can interact. Learning companions enhance learning outcomes by providing help when needed, by challenging a student to reflect on and provide justifications for her actions, and providing opportunities for teaching, which itself can be a powerful motivator. Studies by Jonassen and Li (1996) demonstrated that students learning certain kinds of skills like argumentation need to articulate their own thinking and reasoning like experts do. Chi et. al. (2000) demonstrated that students showed improved performance in solving physics problems when they were encouraged to explain solutions to solved problems. Encouraging students to reflect on their actions and past performance helps them learn from their mistakes, rethink decisions, and restructure their knowledge, making connections where they might not have before. Students learning with peers get opportunities for reflection in a non-authoritative, and therefore, non-threatening context. Where a tutor-student relationship has a clearly defined differentiation of roles, a peer relationship allows a student to try several roles. Virtual learning companions offer some of the benefits of such collaborations with peers in the context of an individualized, self-paced, computer-based training system. The advantages of virtual companions over real companions are that they are always available, they can be engineered to suit the needs of a student, and can evolve with the student.

An example of this is the learning companion, called LuCy, developed by (Goodman et. al. 1998). LuCy is a part of a learning environment for teaching explanatory analysis skills in the domain of satellite activity, where
explanatory analysis is the process of formulating explanations for past or predicted events. This is a skill where reflective thinking is crucial. This system includes an intelligent tutor that is available to the student for assessment, feedback, and instruction. While the role of the tutor in this application is to provide straightforward feedback for a student’s actions, the role of the learning companion is to draw the student to reflect on her actions and to articulate her thought process. For example, if the student assigns an incorrect causal attribution to an event, the tutor would simply respond by stating that this action is incorrect along with an explanation, whereas LuCy would respond with a statement of the form “I don’t think that was a good idea. Why did you do that?” The student would have to respond to this with a justification which, in turn, could lead to further dialog. Thus, the interactions with LuCy contrast with those with the tutor in being more interactive and dialog-oriented with room for give and take of ideas. LuCy is also designed to provide incorrect information at times. Thus, students not only have to justify their own positions, but also evaluate the validity of LuCy’s statements and challenge her appropriately.

The EduAgents environment is another example of a system with learning companions (Pentti and Niemirepo, 1998). This system to help teach elementary school math includes four virtual agents with different expertise levels and personality characteristics. This includes a combination of weakly competent and strongly competent agents, and agents that were hesitant or confident. In addition, two of the agents were boys and two were girls. The authors studied the effect of the expertise level and personality of a companion on students. They found that there were motivational benefits of including agents of varying personality types. They also found that some students preferred to work with learning companions that were hesitant while others preferred the more confident companions. Additionally, the study indicates that students tended to prefer a less competent and hesitant companion in the beginning but moved on to interact with more competent agents as they advanced. This demonstrates that there is no single type of learning companion to suit all learners and they have to be customized to each individual student and her place on the learning curve.

While research shows the promise of such applications of agent technology, this approach has not made its way into fielded educational and training applications.

Typical intelligent tutors tend to be faceless and authoritative, dispensing assessments, advice, and coaching in a disembodied manner. It was hypothesized that making the tutor more life-like would help students feel more engaged with the tutor. With that as the objective, virtual agents have also been used to embody a tutor with face, voice, gestures and emotions. The term “animated pedagogical agents” has been used to refer to such agents. Apart from motivational benefits, pedagogical agents can also be useful for demonstrations and directing the student’s attention to different parts of the environment, and for providing feedback and encouragement to the student with gestures and sound.

Johnson et. al. (2000) discuss some tutors with animated pedagogical agents. One tutor teaches the basics of computer architecture and functions. The other teaches the basics of botany, while a third, Adele, is a web-based tutor for continuing education in family medicine and geriatric dentistry. Steve is an animated pedagogical agent embedded in the tutor for tasks such as operating the engines aboard Navy surface ships (Johnson and Rickel, 1998). All these agents walk (with the exception of Adele) and talk, navigating the environment, providing explanations, and pointing to things to draw the student’s attention. They use various speech and gesture as cues for providing feedback. For example, an agent will nod in agreement to show encouragement, or look quizzical and puzzled when the student does something unexpected. This sort of non-verbal feedback has the advantage of being unobtrusive and non-specific. The student can notice the agents look of puzzlement and themselves determine the cause without being told explicitly what they did wrong.

Studies have shown that students engaging with learning environments with an animated pedagogical agent show statistically significant learning gains, thus countering the criticism that such agents would serve to distract a student. In addition, it was found that agents that combine multiple modalities and provide multiple levels of advice lead to greater learning gains than agents that are less expressive. Finally, the studies also showed a positive correlation between problem-complexity and the presence of an animated pedagogical agent (Johnson et. al., 2000).

VIRTUAL AGENTS TO SUPPORT LEARNING BY TEACHING
There is a Japanese proverb: “To teach is to learn.” Biswas et al., (2001) report that their classroom experience has shown that students preferred preparing presentations for outside audiences and tutoring younger students over preparing for tests. Students who had to teach other students also reported that the responsibilities of teaching made them try to understand the subject on a deeper level. Research on mentoring has shown that tutors learn as much as the students (King, 1998), that well-scaffolded lessons where students tutor each other are beneficial (Palinscar and Brown, 1984; Chan and Chou, 2000) and that one-on-one tutoring is beneficial to both student and the tutor (Chi et al., 2000). Yet there are few opportunities for this kind of learning in a traditional classroom setting. It is possible to pair students so that the more advanced of the pair tutors the other but there are several drawbacks to this approach. First, the student tutor, while more advanced with respect to the tutee, may not have a complete grasp on concepts or may not have the necessary tutoring skills to address the needs of the tutee. Either case places the tutee at a disadvantage that could lead to misconceptions, confusion or frustration. These student tutors would need a level of coaching and one-on-one attention that could easily overwhelm the resources of a teacher. Such an approach might work better if the student pair had complementary areas of expertise, but this is difficult to ensure especially as the students advance at possibly different rates of learning. Furthermore, with this approach, some students may never get an opportunity to play the role of a tutor. Finally, the demand of tutoring a real student with the accompanying necessity of displaying their own knowledge to a peer may evoke discomfort in some students. With the advance of technology, it is now possible to contemplate the use of virtual tutees for a student tutor with a virtual instructor coaching the student tutor in both the subject matter and presentation. This relieves the human instructor of the task of having to coach every single student tutor. With a virtual tutee, issues relating to the effect of tutoring proficiency of the student tutor on the tutee’s learning are no longer relevant. The virtual tutee or tutees can be engineered to grow with the student to always be only a few steps behind, or even ahead in some cases. Issues relating to discomfort arising from the need to tutor a peer are also overcome. Under-performing students are often not motivated to participate in classroom activities due to lack of confidence, and a lack of hope that they can compete with the rest of the class. Computer-based tutoring systems with virtual agents provide a safe environment for such students and helps boost their confidence. A student’s performance is known only to the teacher and the student. This can also be a benefit to other under-represented groups that often have trouble making themselves visible in a classroom environment.

(Chan and Chou, 1997) describe various types of social learning environments that place students in different roles. They have defined the following dimensions for classifying such environments: the nature of the tutor, tutee and learning companions (R for Real, and V for Virtual), and the role of the participants in the learning process (T for Tutor, L for Learner). There are a number of ways of combining these dimensions depending on the number of participants. Traditional Intelligent Tutoring Systems, for example, would be classified as type RL+VT; i.e., there are two participants – a real learner and a virtual tutor. The virtual learning companion approach described in the previous section can be described as RL+VL+VT. The type RT + VL would define an environment where a real student tutors a virtual learner (learning-by-teaching). RT+VT+VL defines an environment where a real student is guided by a virtual tutor in teaching a virtual learner. Their studies with different types of environments indicate that allowing students to play the role of a tutor is significantly more effective than limiting them to the role of a learner. On the other hand, one cannot do away with placing the student in the role of a learner. Environments where students are given opportunities to play the roles of a tutor and a learner are more effective than those where they spend all their time tutoring virtual agents (Chan and Chou, 1997).

The approach of “learning-by-tutoring” also appeals to certain learning styles where some students learn more by explaining concepts to others. One of the benefits of collaborative learning is that students have opportunities to switch between the roles of a learner and teacher naturally and easily.

The Teachable Agents Group at Vanderbilt University has an ongoing effort in realizing the learning by teaching approach in educational software using virtual agents (Biswa et al., 2001). This application was developed for teaching problem-solving skills in the context of project-based activities. An example of an activity is to monitor a local river for water quality. This application presents the students with a virtual agent who is tasked with the objective of reporting water quality. The agent turns in a faulty report and when quizzed shows a lack of understanding of many of the underlying concepts and principles. Students are then tasked with teaching the agent to do a better job. The environment provides tools for the students to explore the topic and generate and discuss ideas. Once they have spent some time exploring they are given the
opportunity to “teach” the agent. Teaching in this case consists of evaluating and correcting the agent’s response to the quiz which the agent supposedly failed. The students are shown the agent’s answer to each question and given an opportunity to change it. Before they attempt to teach the agent, they are given an opportunity to reflect on their readiness. Students can look up resources before answering to make sure they are correct. Once all students have answered all the questions, they get an opportunity to see the agent take another test after having “learned” from the students. The agent’s performance is determined by the aggregate performance of the class on the quiz. Thus, the students’ performance is translated directly to the agent and makes it appear as if the agent has learned from the students. If the agent fails the test again, students are given another opportunity to teach him. Studies with this simple “learning-by-teaching” approach revealed positive learning outcomes and showed that students were motivated by the goal of helping someone even if it was only a computer generated virtual agent. The researchers plan to enhance this environment with facilities where students can directly manipulate the knowledge structures used by the agent. Thus, students can manipulate the semantic networks used to represent the agent’s knowledge.

As with the previous approaches, the use of virtual agents for “learning by teaching”, or indeed the whole idea of training applications where students learn by teaching, is new and limited to research prototypes. Larger-scale evaluations are needed to study and validate the benefits of this approach.

CONCLUSION

Virtual agents are quite familiar as autonomous entities operating within simulations and 3-D games. In this context, they help make the simulation dynamic and realistic. We have discussed some of the ways in which virtual agents can go beyond the limited role of simulation entities to that of instructional agents with pedagogical roles. Thus, virtual agents can be included in team training applications to play the role of absent team members and, additionally provide feedback and coaching. Virtual agents can be embedded in intelligent tutors as learning companions that encourage students to articulate their thought process. Agents can also serve as virtual embodiments of an intelligent tutor, thus adding a face, a voice, and a personality to the tutor. Finally, virtual agents can be used to provide students with an opportunity to learn by teaching these agents. We have provided one or two examples to illustrate these roles. There are other examples of course, but an exhaustive discussion is outside the scope of this paper.

This paper shows that virtual agents have the potential to significantly enhance computer-based learning experience. Training systems using these diverse types of agents are however rare and often only found in research prototypes. It is hoped that this technology will be implemented more extensively in fielded intelligent tutoring environments, providing opportunities for large-scale evaluation of their benefits.

REFERENCES


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