Agent-based learning environments as a research tool for investigating teaching and learning

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Abstract

By using intelligent agents to simulate instruction, agent-based learning environments can serve as a powerful research tool to investigate teaching and learning. The agent metaphor provides a way operationalize and simulate the "human" aspect of instruction in a more ecologically valid way than other controlled computer-based methods. Additionally, from an architectural perspective, since agents are independent objects in the learning environment, it allows for more flexibility in research design. In particular, agent-based learning environments with ***multiple*** agents, in systems such as MIMIC (Multiple Intelligent Mentors Instructing Collaboratively), allow for investigating the effect of multiple mentors or multiple perspectives on a learning topic. Preliminary results from MIMIC research indicate that multiple agents can serve to effectively operationalize instructional theory. In terms of overall impact, creating agent-based learning environments to investigate instructional issues is at the leading edge of revitalized research integrating artificial intelligence with education, and in exploring new paradigms for researching teaching and learning.

As artificial intelligence-enhanced computing is revitalized as a focal point for several research programs and enterprise involvement world-wide, the creation of intelligent systems for educational purposes is of great interest. Intelligent learning environments, such as agent-based learning environments, have distinct advantages over a human-based approach to instruction.

Consider the following:

1. the learner can take as much time as needed
2. the learner can learn at her convenience
3. the learner can adjust the interactions according to her preferences
4. the learner is encouraged to reflect on her thinking processes
5. the learner has a willing collaborator if desired for the learning process
6. the learner has a selection of teachers at her disposal.

Thousands of Web-based courses and other educational applications have been made available on the Web within the last five years. However, the majority of sites consist of static hypertext pages, meeting above features #1 and #2. The challenge is to develop advanced Web-based educational applications that offer interactivity and adaptability (features #3 through #6), which an agent-based learning environment could offer.

While intelligent agent technology provides exciting possibilities for computer-based learning environments, it also provides unique support for instructional research. The metaphor of an intelligent agent is that it is an independent computer program with a persona that simulates a human relationship (Seiker, 1994). The particular focus here is on the value of the metaphor of an intelligent agent for its potential to investigate instructional theory as a pedagogical mentor (see Baylor, 2000a), a simulated instructor, or as a learning companion. Consider how we could research instructionally-relevant issues through the use of agent based learning environments. Through an agent-based learning environment agents could be used to <u>instantiate</u> instructional theories, to serve as pedagogical agents for the main purpose of educational research. Of course, it is important to note there are significant difficulties in developing pedagogical expertise in an intelligent agent. As McArthur, Lewis and Bishay (1993) state, the pedagogical component of intelligent systems receives relatively little mention with current systems demonstrating little pedagogical expertise. However, for the purpose of research it is not required that the agents be especially " intelligent," but rather that they simulate certain characteristics of an intelligent mentor, such as interactivity, expressiveness, controlled feedback. With an agent-based learning environment, there is the potential to incorporate "virtual" learner-agents with whom to collaborate and multiple computer-based instructors, all leading to a rich environment for experimentation.

Why agent-based learning environments?

There is significant potential for agent-based learning environments as a vehicle to research instructional theory for several reasons: 1) the researcher has more control over the learning environment and interactions than in a classroom setting; 2) agents are independent objects in the system, lending to more flexibility and interactivity; 3) while a computer agent can never simulate a real human instructor, agents can better operationalize the human aspect of instruction than other computer-based methods; 4) agent-based systems provide the potential to capture a large amount of rich data, both quantitative and qualitative (while more data is not necessarily better, the possibilities to collect useful information during the instructional process is greatly enhanced); and,

5) through designing agent-based learning environments with ***multiple*** agents, it allows for investigating the effect of ***multiple perspectives or multiple mentors***

Research in intelligent agent-based learning environments tends to focus on system development and implementation rather than controlled assessment of learning effectiveness. For example, a recent special issue on agent-based systems in the Journal of Interactive Learning Research (1999, v10(3/4)) included articles in three areas as described by the editors (Arroyo & Kommers, 1999, p. 235): 1) historical development of intelligent tutoring and support systems; 2) agent paradigms and agent-based user support systems; and, 3) tendencies in agent development and application, including agents as guides, information assistants, architectural solutions, help systems, and as simulation agents in virtual and interactive learning environments. Of the eleven articles in the issue, only three focus on the ***research of instructional issues*** using agents or agent-based learning environments. Of the three articles, only two include controlled empirical studies to test instructionally-related hypotheses. While this is just one journal issue, it underlies the need for more investigation to support the ***educational value of agent-based learning environment development techniques***. Consequently, the review will be limited to research on agent-based research that is ***instructionally-relevant*** with the focus on the value of the agents to simulate instructional interactions. Issues regarding agent architecture will not be discussed, but are of course important.

Even though intelligent agents are currently being developed for educational purposes (e.g., see Baylor, 1999b, 1999c; Baylor & Jafari, 1999, 2000), the instructional value of the use of agents lacks empirical support in three areas: 1) appropriate agent-mentor characteristics; 2) the amount, timing, and appropriateness of agent feedback; and, 3) the effects of dealing with and/or having access to multiple agents within the learning environment. Through an agent-based environment these three variables can be manipulated in order to experimentally determine which are most effective from an instructional standpoint. The key advantage for using agents to provide this functionality is that they are independent objects, with self-contained pedagogical strategies that do not need to be managed by a separate "pedagogical manager" as in traditional intelligent tutoring systems.

Educationally appropriate agent-mentor characteristics

The original conception of an intelligent agent was as a personal butler or assistant (Negroponte, 1970) and many research programs are implementing agents in this capacity to assist in learning (e.g., El-khouly, Far, & Koono, 1999; Whatley, Staniford, Beer, & Scown, 1999; White, Shimoda, & Frederiksen, 2000). However, to be an effective mentor for learning, (Baylor, 2000a) describes two main requirements for agents as mentors: 1) regulated intelligence; and, 2) the existence of a persona.

According to (Baylor, 2000a), while agents as mentors should behave intelligently (in the artificial intelligence sense), similarly to non-educational intelligent agents, ***it is critical for this intelligence to be moderated differently***. While a mentoring agent must demonstrate competence to the learner, in order to be effective the mentoring agent should not be ***too*** intelligent (e.g., see Salomon, Perkins, & Globerson, 1991) because this may lead the user to have unrealistic expectations, a loss of control and limited understanding as to the agent's reasoning. According to this principle, agents should be designed according to the amount of control the user will have on a instructivist-constructivist dimension (Baylor, in press).

Additionally, agents as mentors ***must have an educationally appropriate persona*** (Baylor, 2000a). But should the agent(s) be portrayed as human? It may be important that the agent resemble a human tutor in terms of motivational qualities, such as demonstrating empathy (Lepper & Chabay, 1987). Laurel (1990; 1997) suggested that they could be figurative "actors" in a play that could represent different points of view. She argues for agents to have explicit roles so as to facilitate realistic expectations from the user's perspective. While a risk in comparing agents to humans is that they may become limited to human terms such as "intelligent" or "smart" (Shneiderman, 1997), actually people tend to have exaggerated expectations about what an agent can or should do (Norman, 1997). Further, Reeves and Nass (1996) suggest that people treat computers as human, even when the computer interface is ***not*** explicitly anthropomorphic. For example, Laurel (1997) reports that one interface designer has described error messages as "wrist-slapping grannies."

One way to mediate the human-agent relationship is to promote competence and trust of the agent(s) by the user (Maes, 1997). In Maes (1997) approach, the agent gradually develops its abilities so that the user is also given time to gradually build an understanding of how the agent makes decisions, thereby improving trust. The agent acquires competence from four sources: monitoring the user, noticing his/her behavior; providing direct and indirect user feedback; training from examples given explicitly by the user; and, asking for advice from agents that assist others with same task. Along this line, it may not be appropriate for the agent to be sophisticated, qualified and autonomous from the start (Baylor, in press; Maes, 1994). Shneiderman (1992) suggests that such an agent would leave the user with a feeling of loss of control and understanding. Other human? like qualities that have been attributed to agents include ***responsiveness*** and the ***capacity to perform actions*** (Laurel, 1997), and the capability to provide ***reassurance*** for the user (Norman, 1997). Overall, the learner must feel confident that the agent will perform the desired task and that the agent interpreted the desired task correctly. But how much confidence is necessary from an educational perspective?

Several of the human-like qualities attributed to agents require agent expression of emotion. But how should this be implemented? To what extent is it educationally valuable for the agent to be believable? As stated by Bates (1994) emotion is a key method to achieve believability, because it allows the agent-characters to demonstrate that they really care about what happens in the world, that they truly have desires. In terms of empirical evidence, initial results suggest the value of agent expressiveness. Lester, Converse, Kahler, Barlow, Stone, & Bhoga (1997) tested the affective impact of animated pedagogical agents by implementing an agent that offered various types of feedback during a learning task. They found that learners preferred the agent in the fully expressive condition (where all types of feedback were present) to all other conditions (which offered limited types of feedback). Further, performance on the learning task was best in the fully expressive condition. Koda & Maes (1996) suggest that more expressive agents have greater motivational impact. However, Dietz & Lang (1999) found that while users preferred agents showing more emotion and performed better on a memorization task with the emotion-showing agents, the results were not statistically significant. Further research is necessary to determine implementations of emotion that are most desirable for the learner from an educational perspective.

Further, how should agents be graphically represented? Shneiderman (1992) suggests that user interfaces should not attempt to mimic human interaction but maintain a "neutral" status. This would suggest that the agent should be portrayed with graphic or iconic representations rather than realistic animations or video. A good compromise may be the use of different faces, which Maes (1997) describes in an email agent application. Specifically, the agent has different faces to indicate what the agent is doing: thinking, working, suggesting, unsure, pleased, confused. However, life-like agents, such as Microsoft's conversational parrot "Peedy" (Ball et al., 1997), or Lester & Stone's (1997) "Herman the Bug" in the Design-a-Plant learning environment have not been compared too non-lifelike counterparts in a controlled research environment. In terms of the value of lifelike, animated agents, Johnson, Rickel, and Lester (2000) explain, "these lifelike autonomous characters cohabit learning environments with students to create rich, face-to-face learning interactions. This opens up exciting new possibilities; for example, agents can demonstrate complex tasks, employ locomotion and gesture to focus students' attention on the most salient aspect of the task at hand, and convey emotional responses to the tutorial situation."

Agent feedback

Glass Boxes, not Black Boxes

As Malone, Lai & Grant (1997) propose, usually computer systems are at one extreme or the other: either highly structured such as databases with strict requirements and structured procedures, or non-structured such as word processing where the computer's role is to record, store and transmit information without having to "understand" or process the information it stores. They propose a semiformal systems approach where the information is semi-structured with the reasoning visible to the learner. In other words, rather than creating intelligent agents whose operations are "black boxes," designers should try to create "glass boxes" where the essential elements of the agents' reasoning can be seen and modified by learners (Malone et al., 1997).

A related issue when considering the agents' role in providing an instructional environment is in terms of how active the agents should be to provide explanations of their pedagogical behavior. Assuming that the agents do have some planning role in the instructional environment, does the learner needs understanding of what happened pedagogically and why? One advantage of providing explicit teaching strategy differences from the mentoring agents to the learner (as opposed to being built-in to the system and invisible to the learner) is that it can facilitate reflective thinking (e.g., Baylor & Kozbe, 1998). Information processing models of cognition (e.g., Pressley & McCormick, 1995) suggest the primary importance of metacognitive skills, particularly as metacognitive ability is a feature of expert problem solvers (Glaser & Chi, 1988). But as Erickson (1997, p.83) proposes:

> Consider an intelligent tutoring system that is teaching introductory physics to a teenager. Suppose the system notices that the student learns best when information is presented as diagrams and adapts its presentation appropriately. But even as the system is watching for events, interpreting them, and adjusting its actions, so is the student watching the system, and trying to interpret what the system is doing. Suppose that after a while the student notices that the presentation consists of diagrams rather than equations: it is likely that the student will wonder why: ?Does the system think I'm stupid? If I start to do better, will it present me with equations again?' There is no guarantee that the students' interpretations will correspond with the system's.

How can such potentially negative misunderstandings on the user's part be minimized? The trick seems to be in resolving the learner's need for explanations from the system with the need to formulate his/her own explanations. And the solution to this dilemma can be simple, depending on the context. Furthermore, as Negroponte (1997) suggests, the human act of winking can connote a lot of information to others simply in the ***lack*** of information.

Because of the importance of sharing the agent's reasoning with the learner, the issue of feedback is critical (Baylor, in press). As Erickson (1997) points out, the user needs understanding of what happened and why. Keeping this issue at the forefront, Baylor & Kozbe (1998) developed initial specifications for an intelligent agent, the Personal Intelligent Mentor (PIM), that has special potential for tapping learners' metacognitive processing. As a pedagogical expert the intelligent agent could serve as a technological "reciprocal teacher" (e.g., Palinscar & Brown, 1984), prompting the individual to engage in analysis of his/her own cognitive processes. This use of an intelligent agent would serve to encourage the individual to assess what cognitive strategies are being used, similar to Salomon's pedagogic computer program, the Writing Partner (Salomon, 1993), which asks the learner intelligent questions through the writing process.

The amount and timing of the feedback

In terms of the amount of feedback, it is important that the agent does not provide so many insights that it annoys the student. Given that an act such as winking can connote a lot of information without providing explicit details, there are ways for the pedagogical agent to provide more judicious feedback. To monitor of the timing and implementation of the advisements, the principle of minimal help could allow the student to ***select*** a feedback option depending on the amount of structure, interaction, and feedback s/he desires when problem-solving. If the agent could fade and allow more student initiative as the student gains expertise, it could also address this issue.

The effects of multiple agents within a learning environment

A promising possibility in terms of regulating pedagogical interventions is the instantiation of ***multiple*** pedagogical agents in a learning environment. In this sense, building beyond Laurel's (1990; 1997) suggestion to have agents represent roles or characters in a play, agents for learning could represent different ***instructional*** roles. While this idea has been implemented in other research, there have been no controlled studies. For example, The Guides project (Oren, Salomon, Kreitman, & Don, 1990; Salomon, Oren, & Kreitman, 1989) looked at multiple perspectives of history in a computer-based program, but only provided anecdotal information. Lampert and Ball (1990) developed a hypermedia system to represent teachers' thinking about mathematics and their pedagogical decisions, with annotations to analyze lessons from the perspective of relevant academic disciplines. Krajck (1996) developed a Casebook of Project Practices (CaPPs) to help teachers learn a constructivist approach to science teaching, but without an opposing instructivist perspective. The ETOILE system for teaching educational psychology principles, by Dillenbourg, Mendelsohm, and Schneider (1994), includes five teaching agents, labeled after the teaching styles they implement: Skinner, Bloom, Vygotsky, Piaget, and Papert. In ETOILE, however, the pedagogical roles of the agents are separated out from the content, instead of being content-specific.

Operationalizing multiple perspectives

Viewing a situation or problem from multiple perspectives is desirable for promoting reflective thinking and problem solving, qualities important when teaching students how to be scientific researchers. For example, multiple perspectives in science/math helps underrepresented students to see their potential in science in a more positive way (Behm, 1996). Further, the ability for a learner to take multiple perspectives on ill-structured problems (e.g., instructional design or scientific inquiry) is beneficial when more than one problem-solving path is possible to reach a solution. It is beneficial for pre-service teachers to see their role in the classroom from multiple perspectives (Bennett & Spalding, 1992). Along this line, the presence of multiple agents could challenge pre-service teachers' beliefs about instruction, or facilitate the reconciliation of diverse views about use of technology in the classroom. Hietala & Niemirepo (1998) suggest that the same social factors that occur in learning communities with human beings are also influential in a learning community consisting of multiple artificial teaching and learning agents. They refer to this aspect as the need for pedagogical multiplicity of teachers, suggesting that the many levels and complexities of the learning process might be alleviated by providing more alternatives to the learner via an "extended family of intelligent agents." However, there is little controlled research systematically investigating learning with multiple pedagogical agents.

Overall, some key areas for further research include agent characteristics, agent feedback and multiple-agent approaches. Additionally, the design of agent-based learning environments themselves impacts basic research in learning and instruction. For example, in attempting to simulate human expert mentors, questions must be examined such as the following: What are the features of expert human mentors and how do they affect the development of engaging agent mentors (e.g., Laurel, 1997)? Further, how can we implement computer-based interaction principles (e.g., graphical user interface, agent "personality," visual appeal) that incorporate usability principles and understanding of the user without distracting him/her? In terms of balancing user vs. system control, questions to consider include how can we balance user vs. system control in agent-based learning environments (see Baylor, in press) so as to facilitate constructivist learning experiences while allowing for systematic instructional planning of the underlying system (Akhras & Self, 2000)? From a more technical perspective, there is the challenge of modeling agent-agent and user-agent collaboration. How can we design collaboration between the system and user so as to reflect the interactions characteristic of expert instructional intervention? Or, how does this collaboration compare to human-based collaboration in learning with technology (e.g., Bonk, 1998)?

As a start to investigating these issues, the next section will discuss the background for Multiple Intelligent Mentors Instructing Collaboratively (MIMIC), an agent-based environment developed for the purpose of researching teaching and learning. After presenting an overview of the underlying framework, a discussion of preliminary research results will follow.

Example: The current prototype of Multiple Intelligent Mentors Instructing Collaboratively (MIMIC)

Context

In the field of instructional design, there are diverse theories and approaches to instruction (e.g., Driscoll, 2000). For teaching professionals, the importance of seeing how these theories relate to real instructional problems is critical. Having several experts describing the instructional content matter from different points of view can be very rewarding for the learner (Laurel, Oren, & Don, 1990) and can help the learner to establish the best personalized approach to understanding the content. If a pre-service teacher (PST) could confront multiple instructional theories simultaneously via pedagogical agents, how would this affect her performance in applying instructional design principles to an authentic problem, and her corresponding beliefs and attitudes about the theories? What characteristics of such an instructional environment (e.g., presence of a particular pedagogical approach, number of pedagogical agents, or combination of agents) best promote learning and motivation?

These questions are currently being investigated with the MIMIC (Multiple Intelligent Mentors Instructing Collaboratively) learning environment, as shown in Figure 1, where pre-service teachers learn about approaches to instructional planning through interacting with agent-mentors. In other words, the environment contains simulated teachers (agent-mentors) teaching pre-service teachers about teaching (instructional planning). In MIMIC, the agents instantiate instructional theories for the purpose of investigation.

The current phase of MIMIC consists of two pedagogical agents that represent contrasting approaches to designing instruction (Jonassen, 1991):

? The ***Instructivist*** reflects a teacher-driven approach, including the problem-solving aspects of Instructional Systems Design (ISD) as characterized by Dick & Carey (1996) and Reiser & Dick (1996).

? The ***Constructivist*** reflects learner-centered approaches, focusing on the importance of the context of learning, stressing that learning involves active interaction, and emphasizing the process rather than the product of learning (Driscoll, 2000).

Of course there is overlap across the two perspectives, which is accounted for in the agents' interactions. To form a basic structure for the environment, verbal protocol analyses were conducted for three pre-service teachers as they talked-aloud through designing instruction for the case study. The next section will describe a sample agent-user interaction within the system.

Example user-agent interaction:

The context is that the PST (pre-service teacher) has just entered <The Plan> page, where she will develop an instructional plan within MIMIC. The PST does not know the purpose of the two agents (here referred to as Instructivist and Constructivist) in terms of pedagogy; they are just there to assist her. In this example both agents are present?

Instructivist: " When you start to develop the activities, consider what Anna should know and what Anna will do with that knowledge" <waits with a light bulb and a box stating: " Click me once for more detailed suggestions." >

Constructivist: “ I would start by coming up with a market that the students can relate to? something like Pokeman” <waits with a light bulb and a box stating: “ Click me once for more detailed suggestions.” >

PST <clicks on (Suggestion from Instructivist) >

Instructivist: “ How I would start would be to consider the basic economics laws and definitions and consider what knowledge is involved for each: 1) law of supply; 2) law of demand; 3) law of price change”

Constructivist: “ But do you think they will really understand these concepts? Maybe the students won’t ?get it’ just from the definitions and the laws. I think they need to interact with the information.. Maybe even they could figure out the laws for themselves!”

PST <after working on her plan for a few minutes, she clicks on (Blueprints), to go to a prior page that includes her instructional goals>

Instructivist: “ That’s a good idea to review the goals of the instruction.”

Constructivist <after PST works without intervention for 10 minutes > “ Why don’t you take a moment to look over what you have done so far? consider what you think about it..”

? and so on...

Cognitive foundations of MIMIC

To account for the important issue of agent and user control within agent-based learning environments, the following four considerations were addressed, as described in Baylor (in press): 1) the instructional purpose of the system is as a scaffold for the learner, with high learner control and lower agent control (thus eliminating the need for significant agent intelligence); 2) the feedback is primarily initiated by the learner, where s/he requests a suggestion from an agent ; 3) the agent-learner relationship is defined with the agents serving as multiple instructional mentors; and, 4) learner confidence in the agents is facilitated by believability — through implementing the agents as 3-dimensional, animated, and expressive using Microsoft Agent -- and by agent competence — through formulating the agent advisements to reflect best practices in instructional theory.

To further enhance believability, the agents’ providing feedback that underlined the discourse structure (such as turning head and eyes towards the user when expecting a request by the user or averting gaze when executing a command). Based on findings from Cassell and Thorisson (1999), subjects rated the smoothness of the interaction as well as the agents' language skills in the discourse-supporting feedback condition significantly higher than agents that just provided answers with and without emotional responses.

An initial area investigated within MIMIC is regarding learner confidence with the agents as pedagogical mentors. The next section will report preliminary results from research related to the credibility and effectiveness of multiple agents as pedagogical mentors.

Investigating learner confidence with multiple pedagogical agents in MIMIC

Research questions

The research questions for this preliminary study follow:

1) Will participants find the agent-mentors annoying or useful? Further, will they pay attention to the agent-mentors' suggestions?

2) Will participants find the agent-mentors to be credible? Will there be differences between agent-mentors?
3) Will participants discern the pedagogical differences between the agent-mentors?

Sample

The sample consisted of 43 pre-service teachers in an "Introduction to Educational Technology" course. The mean age of the sample was 19.70 years (SD=1.19). In terms of prior experience with instructional planning, participants' mean score was 2.23, (SD=.97), where 1=no experience and 5=very much experience, indicating that overall they had little prior experience.

Procedure

The content basis of the MIMIC agent-based environment is a multimedia-enhanced case study of an imaginary student and her eighth grade class that is having difficulties learning the economic concept of "supply and demand". The task is for the pre-service teacher to design instruction (consisting of three phases: goals/blueprints, instructional plan, and assessment) within the environment to address this problem. At any time it was possible for the participant to move from one phase to the other.

All 43 participants worked in the environment with both the instructivist and constructivist agents present, but were unaware of their underlying pedagogy (e.g., the agents were referred to by the gender-neutral names of "Chris" and "Jan"). The agents were intended to serve as mentors and to operationalize the instructivist and constructivist approaches to instructional planning. Each agent provided the following: 1) an initial observation regarding the current phase of the instructional plan; and, 2) additional suggestions (i.e., agent advisements), as requested by the participant by clicking on the agent. Additional suggestions were organized according to possible questions for the participant to request that the agent answer. See Table 1 for a complete description of agent advisements. Agent advisements were developed and validated by experts in instructional planning together with the consultation of an economics professor.

After completing the instructional plan within the two-agent MIMIC environment, participants were asked questions in the following areas: 1) usefulness of the agents; 2) credibility of the agents; and, 3) discernment of pedagogical differences between the agents.

Results

Usefulness of agents. When asked "Overall, was <agent> annoying or useful?" on a forced-choice scale of (Extremely annoying / annoying / useful / very useful), participants tended to select "useful" for both agents, and there were no statistically significant differences between the two agents as tested by a paired t-test. When asked "Did you pay attention when <agent> made suggestions?" on a scale of (Not at all / Not usually / Usually / Always), participants' answers averaged near "usually" for both agents, and there were no statistically significant differences in paying attention between the two agents as tested by a paired t-test.

Credibility of agents. In terms of whether participants agreed with the agents, they were asked for each agent "Did you generally agree with <agent>'s suggestions? (yes/no)" There were statistically significant differences for each agent as indicated by chi-squares: for the instructivist agent, $X^2 = 5.23$, $p<.05$ where 29 agree and 14 disagree; for the constructivist agent, 34 agree and 9 disagree, $X^2=14.54$, $p<.001$.

Twenty of the 29 respondents who agreed with the instructivist agent provided answers to the next question: "Why <did you agree with instructivist agent's suggestions>?" . These 20 participants validated the instructivist agent according to seven reasons, which were categorized by the researcher (with % of respondents in parentheses):

- Guided, structured, precise plan (45%)
- Good ideas (25%)
- Reminded me of things I'd forgotten (10%)
- Made me think (5%)
- Related ideas to students (5%)
- Did not rely on group activities (5%)
- Followed guidelines taught in class (5%)

Clearly, those respondents who agreed with the instructivist agent preferred its structured plans, which is a major characteristic of the instructivist planning approach, and they had the vague notion that the ideas were "good". The fact that the instructivist agent could remind respondents of ideas they had forgotten could possibly be attributed to its focus on structured plans.

Twelve of the 14 respondents who disagreed with the instructivist agent provided answers to the question: "Why <did you agree with instructivist agent's suggestions>?" These 12 participants cited the following seven reasons, which were categorized by the researcher (with % of respondents in parentheses):

- Went by the book, was less creative and more structured (33%)
- Wanted to be the head of instruction (17%)
- Too complicated (17%)
- Boring ideas (17%))
- Too many rules (8%)
- Less involvement with students (8%)

These respondents disagreed with the instructivist agent for essentially the same reasons that the previous respondents agreed with the agent, indicating that the instructivist agent effectively characterized and represented the key qualities associated with instructivism.

More respondents agreed with the constructivist agent than with the instructivist agent. A total of 34 respondents agreed with the constructivist agent while only 9 disagreed. Twenty of the 34 respondents who agreed with the constructivist agent provided answers. Their answers were categorized by the researcher into the following 5 categories (with % of respondents in parentheses):

- Group learning, hands-on, involves students, focused on students (50%)
- Fun, creative and good ideas (25%)
- Thought provoking (10%)
- Basic and to the point (10%)
- Uses concepts taught in class (5%)

There were 9 respondents who disagreed with the constructivist agent's approach. Of the 9 respondents who disagreed with the constructivist agent, 6 of them provided a reason for their disagreement. Their reasons were categorized into the following three categories (with % of respondents in parentheses):

- Wasn't clear (67%)
- Too much emphasis on student (16.5%)

- Too brief (16.5%)

Discernment of pedagogical differences between agents. Participant's ability to differentiate between the two agent-mentors was further confirmed by analysis of their answers when they were asked to "Please compare and contrast <instructivist agent> and <constructivist agent>." 41 of the 43 respondents provided opinions on their differences. The majority of opinions (66%) pointed towards accurately labeling the instructivist agent as instructivist and the constructivist agent as constructivist. Only three participants indicated that they did not discern a major difference between the two agents. The opinions that did not center on instructivist vs. constructivist characteristics were vague and stated things like "<the instructivist agent> had better ideas & examples" and "<the constructivist agent> was straightforward and <the instructivist agent> elaborated." When directly asked, "Which agent would you choose if you had to pick one ?" 47% indicated the constructivist agent, and 53% selected the instructivist agent, which was not a statistically significant difference as tested through chi-square analysis.

Discussion

Overall, results from this preliminary study seem to indicate that the pedagogical agents in MIMIC effectively operationalized instructional theory and were useful, credible and worthy of participants' attention. Depending on personal points-of-view, respondents liked one agent-mentor better than the other. Their reasons for agreeing and disagreeing with the two agents show that they thought of the instructivist agent as a structured, "traditional" teacher while the constructivist agent was viewed as more student-centered, creative, and hands-on. It seems clear that the majority of the 43 respondents could discern the pedagogical differences between the two agents and this metacognitive awareness of the agents' pedagogies gives preliminary validity to the utility of agents as mentors.

These results provide a more controlled validation of the believability of multiple agents that promote different perspectives on a situation. Given that the user's confidence in the agents is a key consideration for agent-based learning environments (Baylor, in press), these results help substantiate that the MIMIC pedagogical agents are viable and effective with educationally-appropriate personas, which are key requirements for agents to be effective mentors (Baylor, 2000a).

Future possibilities

Some possibilities for future intervention include the following:

- Customizing the environment based on user epistemology. Based on initial findings regarding pre-service teachers' attitudes and epistemological beliefs, one experimental intervention could be to have the system agent(s) contrast with the pre-service teachers' epistemology, so as to challenge their thinking.
- Varying the agents' persona. In this area, the agents' personality could be varied (to the extent to which it is programmable), emotional expressiveness, or language.
- Varying the agent's pedagogy. Determine impact of a third instructional agent (e.g., "The Artist" who will promote brainstorming, intuition, idea generation), and/or pilot self-regulatory suggestions with the agents as "self-regulation mentors" (building on recent work by Baylor, Kitsantas, & Chung, 2001; Kitsantas & Baylor, in press; Kitsantas, Baylor, & Hu, 2001).

- <u>Improving system functionality.</u> The system will be improved in terms of developing a more flexible agent architecture, more latitude and choice for the user within the environment, and more possibilities for interaction. Along this line, the system will be developed to implement multiple pedagogical agents that are more authentically ***collaborative***. Additionally, an agent toolkit could be developed where the user can choose the pedagogical rules it wants to assign to the agent(s) as a cognitive tool (see Baylor, 1998). This will also build on findings regarding teachable agents by Brophy, Biswas, Katzlberger, Bransford, & Schwartz, (1999) and prior research on instructible agents (Lieberman & Maulsby, 1996).

Continuing experimental investigations with the system will be conducted, for example to implement agent(s) as learning companions as an intervention, and/or to investigate the effectiveness of instructional approaches (or combinations of approaches) to instructional design under different circumstances/scenarios.

Conclusion

In terms of overall impact, creating agent-based learning environments to investigate instructional issues is at the leading edge of revitalized research integrating artificial intelligence with education, and in exploring new paradigms for teaching and learning. Through systems such as MIMIC (Baylor, 1999a, 1999d, 1999e, 2000b), we can strive to better ***mimic*** instruction by developing controlled computer-based environments for investigating teaching and learning.

References

Akhras, F. N., & Self, J. A. (2000). System Intelligence in Constructivist Learning. International Journal of Artificial Intelligence in Education, 2000, 11.

Arroyo, & Kommers. (1999). Journal of Interactive Learning Research, 10(3/4).

Ball, G., Ling, D., Kurlander, D., Miller, J., Pugh, D., Skelly, T., Stankosky, A., Thiel, D., Van Dantzich, M., & Wax, T. (1997). Lifelike computer characters: The persona project at Microsoft. In J. M. Bradshaw (Ed.), Software Agents (pp. 191-222). Menlo Park, CA: MIT Press.

Bates, J. (1994). The role of emotion in believable agents. Communications of the ACM, 37(7), 122-125.

Baylor, A. L. (1998). Intelligent agents as cognitive tools in education. Paper presented at the Association for Educational Communications and Technology, St. Louis, Missouri.

Baylor, A. L. (1999a). Foundations for designing MIMIC, an intelligent agent-based learning environment. Paper presented at the International Conference of Technology in Education (ICTE), Tampa, FL.

Baylor, A. L. (1999b). Intelligent agents as cognitive tools. Educational Technology, 39(2), 36-40.

Baylor, A. L. (1999c). Intelligent agents for education. Paper presented at the American Educational Research Association, Montreal, Canada.

Baylor, A. L. (1999d). Multiple Intelligent Mentors Instructing Collaboratively (MIMIC): Developing a Theoretical Framework. Paper presented at the International Cognitive Technology Conference, San Francisco, CA.

Baylor, A. L. (1999e). Multiple Intelligent Mentors Instructing Collaboratively (MIMIC): An Intelligent Agent-Based Learning Environment for Learning Instructional Design. Invited full proposal to National Science Foundation in Knowledge Distributed Intelligence: Learning Intelligent Systems division, May, 1999.

Baylor, A. L. (2000a). Beyond butlers: Intelligent agents as mentors. Journal of Educational Computing Research, 22(4), 373-382.

Baylor, A. L. (2000b). A framework for MIMIC, an intelligent agent-based learning environment. Paper presented at the Association for Educational Communication and Technology, Long Beach.

Baylor, A. L. (in press). Permutations of control: Cognitive guidelines for agent-based learning environments. Journal of Interactive Learning Research.

Baylor, A. L., & Jafari, A. (1999). What are the possibilities of intelligent agents for education? Paper presented at the International Conference of Technology in Education (ICTE), Tampa, FL.

Baylor, A. L., & Jafari, A. (2000). Intelligent agents for education: Possibilities and realities. Paper presented at the Association for Educational Communication and Technology, Long Beach.

Baylor, A. L., Kitsantas, A., & Chung, H. (2001). The Instructional Planning Self-Reflective Tool (IPSRT): A Method for Promoting Effective Lesson Planning. Educational Technology.

Baylor, A. L., & Kozbe, B. (1998). A personal intelligent mentor for promoting metacognition in solving logic word puzzles. Paper presented at the Workshop "Current Trends and Applications of Artificial Intelligence in Education" at The Fourth World Congress on Expert Systems, Mexico City, Mexico.

Behm, C. (1996). Connections across Cultures: Inviting Multiple Perspectives into Classrooms of Science, Technology, Math, and Engineering, ERIC reference ED408171.

Bennett, C., & Spalding, E. (1992). Teaching the Social Studies: Multiple Approaches for Multiple Perspectives. Theory and Research in Social Education, 20(3), 263-292.

Bonk, C. (1998). Electronic Collaborators. Mahwah, NJ: Lawrence Erlbaum.

Brophy, S., Biswas, G., Katzlberger, T., Bransford, J., & Schwartz, D. (1999). Teachable Agents: Combining Insights from Learning Theory and Computer Science. Paper presented at the AI-ED 99, LeMans, France.

Cassell, J., & Thorisson, K. R. (1999). The power of a nod and a glance: Envelope vs. emotional feedback in animated conversational agents. Applied Artificial Intelligence, 13(4-5), 519-538.

Dick, W., & Carey, L. (1996). The systematic design of instruction: Addison-Wesley Longman.

Dietz, R. B., & Lang, A. (1999). Aeffective agents: Effects of agent affect on arousal, attention, liking and learning. Paper presented at the International Cognitive Technology Conference '99, San Francisco, CA.

Dillenbourg, P., Mendelsohn, P., & Schneider, D. (1994). The distribution of pedagogical roles in a multiagent learning environment. In R. Lewis & P. Mendelsohn (Eds.), Lessons from learning (pp. 199-216): Elsevier.

Driscoll, M. P. (2000). Psychology of Learning for Instruction: Allyn & Bacon.

El-khouly, M., Far, B., & Koono, Z. (1999). Agent-based computer tutorial system: An experiment for teaching computer languages. Journal of Interactive Learning Research, 10(3/4), 275-286.

Erickson, T. (1997). Designing agents as if people mattered. In J. M. Bradshaw (Ed.), Software Agents (pp. 79-96). Menlo Park, CA: MIT Press.

Glaser, R., & Chi, M. (1988). Introduction: What is it to be an expert? In M.Chi & R. Glaser & M. Farr (Eds.), The nature of expertise (pp. xv-xxiix). Hillsdale, NJ: Erlbaum & Associates.

Hietala, & Niemetirepo. (1998). Paper presented at the Presented at Workshop "Current Trends and Applications of Artificial Intelligence in Education" at The Fourth World Congress on Expert Systems, Mexico City, Mexico.

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

Jonassen, D. H. (1991). Evaluating Constructivistic Learning. Educational Technology, 31(9), 28-33.

Kitsantas, A., & Baylor, A. L. (in press). The Impact of the IPSRT (Instructional Planning Self-Reflective Tool) on Pre-Service Teachers' Performance, Disposition, and Self-Efficacy Beliefs Regarding Systematic Instructional Planning. Educational Technology Research & Development.

Kitsantas, A., Baylor, A. L., & Hu, H. (in press). The Constructivist Planning Self-Reflective Tool (CPSRT): Facilitating a constructivist instructional planning approach. Educational Technology.

Koda, T., & Maes, P. (1996). Agents with face: the effects of personification of agents. Paper presented at the HCI '96, London, UK.

Krajck, J. S. (1996). The Casebook of Project Practices--an Example of an Interactive Multimedia System for Professional Development. Journal of Computers in Mathematics and Science Teaching, 15(1/2), 119-135.

Lampert, M., & Ball, D. (1990). Using Hypermedia Technology to Support a New Pedagogy of Teacher Education (Paper 90-5): National Center for Research on Teacher Education, 116 Erickson Hall, College of Education, Michigan State University.

Laurel, B. (1990). Interface agents: Metaphors with character. In B. Laurel (Ed.), The art of human-computer interface design. Reading, MA: Addison-Wesley.

Laurel, B. (1997). Interface agents: Metaphors with character. In J. M. Bradshaw (Ed.), Software Agents (pp. 67-78). Menlo Park, CA: MIT Press.

Laurel, B., Oren, T., & Don, A. (1990). Issues in multimedia interface design: Media integration and interface agents. Paper presented at the CHI'90 Human Factors in Computing Systems.

Lepper, M. R., & Chabay, R. W. (1987). Socializing the intelligent tutor: bringing empathy to computer tutors. In H. Mandl & A. Lesgold (Eds.), Learning issues for intelligent tutoring systems (pp. 242-257). New York: Springer-Verlag.

Lester, J. C., Converse, S. A., Kahler, S. E., Barlow, S. T., Stone, B. A., & Bhoga, R. S. (1997). The persona effect: affective impact of animated pedagogical agents. Paper presented at the CHI97 Human Factors in Computing Systems.

Lester, J. C., & Stone, B. A. (1997). Increasing believability in animated pedagogical agents. Paper presented at the In the First International Conference on Autonomous Agents.

Lieberman, H., & Maulsby, D. (1996). Instructible agents: Software that just keeps getting better. IBM Systems Journal, 35(3/4), 539-556.

Maes, P. (1994). Agents that reduce work and information overload. Communications of the ACM, 37(7), 31-40.

Maes, P. (1997). Agents that reduce work and information overload. In J. M. Bradshaw (Ed.), Software Agents (pp. 145-164). Menlo Park, CA: MIT Press.

Malone, T. W., Lai, K.-Y., & Grant, K. R. (1997). Agents for information sharing and coordination: A history and some reflections. In J. M. Bradshaw (Ed.), Software Agents (pp. 109-144). Menlo Park, CA: MIT Press.

McArthur, D., Lewis, M., & Bishay, M. (1993). The roles of artificial intelligence in education: Current progress and future prospects (RAND). Santa Monica, CA.

Negroponte, N. (1970). The Architecture Machine: Towards a More Human Environment: MIT Press.

Negroponte, N. (1997). Agents: From direct manipulation to delegation. In J. M. Bradshaw (Ed.), Software Agents (pp. 57-66). Menlo Park, CA: MIT Press.

Norman, D. A. (1997). How might people interact with agents. In J. M. Bradshaw (Ed.), Software Agents (pp. 49-56). Menlo Park, CA: MIT Press.

Oren, T., Salomon, G., Kreitman, K., & Don, A. (1990). Guides: Characterizing the Interface. In B. Laurel (Ed.), The art of human-computer interface design (pp. 367-381). Reading, Mass.: Addison-Wesley.

Palinscar, A., & Brown, A. (1984). Reciprocal teaching of comprehension-fostering and comprehension-monitoring activities. Cognition and Instruction, 1(2), 117-175.

Pressley, M., & McCormick, C. (1995). Advanced educational psychology for educators, researchers, and policymakers. New York, NY: HarperCollins College Publishers.

Reeves, B., & Nass, C. (1996). The Media Equation. Stanford, CA: CSLI Publications.

Reiser, R. A., & Dick, W. (1996). Instructional Planning: A guide for teachers: Allyn and Bacon.

Salomon, G. (1993). On the nature of pedagogic computer tools: The case of the writing partner., Computers as cognitive tools. (pp. 179-196). Hillsdale: Lawrence Earlbaum Associates.

Salomon, G., Oren, T., & Kreitman, L. (1989). Using guides to explore multimedia databases. Paper presented at the Twenty-Second Annual Hawaii International Conference on System Science, Washington, D.C.

Salomon, G., Perkins, D. N., & Globerson, T. (1991). Partners in cognition: extending human intelligence with intelligent technlogies. Educational Research, 20(3), 2-9.

Seiker, T. (1994). Coach: A teaching agent that learns. Communications of the ACM, 37(7), 92-99.

Shneiderman, B. (1992). Designing the User Interface (2nd ed.). Reading, MA: Addison-Wesley.

Shneiderman, B. (1997). Direct manipulation versus agents: Paths to predictable, controllable, and comprehensible interfaces. In J. M. Bradshaw (Ed.), Software Agents (pp. pp. 97-108). Menlo Park, CA: MIT Press.

Whatley, J., Staniford, G., Beer, M., & Scown, P. (1999). Intelligent agents to support students working in groups online. Journal of Interactive Learning Research, 10(3/4), 361-374.

White, B. Y., Shimoda, T. A., & Frederiksen, J. R. (2000). Facilitating students' inquiry learning and metacognitive development through modifiable software advisers. In S. P. Lajoie (Ed.), Computers as Cognitive Tools Vol 2: No More Walls (pp. 97-132). Mahwah, NJ: Lawrence Earlbaum.

Figure 1: Screen shot in MIMIC when participant selects " What is my role in the learning process for Anna?" from the instructivist agent (Jan).

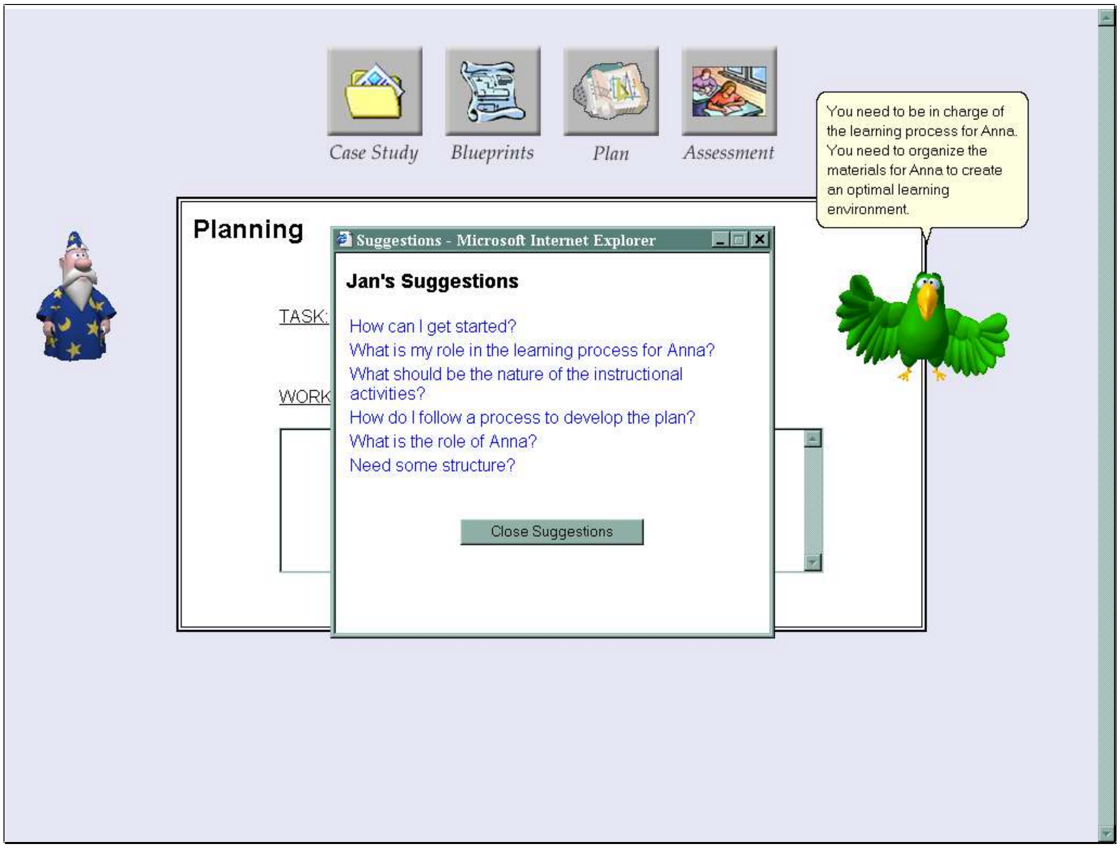

Table 1. List of agent advisements

Location	**Type of advisement**	**Constructivist agent**	**Instructivist agent**
Case study	Initial observation	The concept of supply and demand is not being made real to the students. Perhaps it needs to be presented more realistically so that they can identify it in their own lives?	The instruction is not working because it is not systematically planned-out. There needs to be a better match between what the students need to learn about supply and demand and the actual activities that they do to learn it.
Case study	Additional suggestion	Try to get the students involved and cognitively active in the learning process. From her homework we don't know if she can really USE the information.	Develop a well-designed plan that will clearly determine WHAT she needs to know and exactly HOW to teach her that.
Blueprints	Initial observation	Consider what you want Anna to learn, but leave some room so that she can have some choice.	State your goal as clearly as possible? this is a key step.
Blueprints	Additional suggestion: What is the role of the instructor?	The goals should be created by instructor together with the student. But the instructor must provide constraints for the learner, to guide the process, so that she will not be frustrated.	The instructor (or designer) should create the goals as specific and as clearly as possible.
Blueprints	Additional suggestion: What is the purpose of the goals?	To set the context for learning so that the focus can be on the learning process itself.	To define what the learner must learn so that appropriate learning activities can be designed.
Plan	Initial observation	I believe the goal is for Anna to create the information for herself.	I believe the goal is for Anna to obtain the information from the instructor.
Plan	Additional suggestion: What is my role in the learning process for Anna?	Anna should be at the center of the learning process. This will encourage Anna initiative, get Anna to think and to reflect, and Make the information real for Anna.	You need to be in charge of the learning process for Anna. You need to organize the materials for Anna, to create an optimal learning environment.
Plan	Additional suggestion: What should be the nature of the instructional activities?	In terms of the nature of the activities, you could provide counter-examples to encourage Anna to reflect. Make sure that Anna really understands the economic principles. She won't necessary " get it" just from the definitions. She needs to interact with the laws cognitively.	In terms of the nature of activities, they should be well-planned out in advance to transmit the information to Anna. When developing the activities, consider what Anna should know and what Anna will do with that knowledge.
Plan	Additional suggestion: How do I follow a process to develop the plan?	Consider the ways to facilitate the process: coach, scaffold, cognitive tools, collaboration, and simulation. Develop activities to facilitate the process of learning. There is no ideal process. Try to individualize.	Follow guidelines for instructional activities Present information, present examples, practice and feedback. Start with the basic economics laws and definitions and work from there: This includes the law of supply; the law of demand, and the law of price change

<table>
<tr><td></td><td></td><td></td><td>Just follow the systematic process?
Match the instructional activities to objective; take each objective from the previous phase and create appropriate instructional activities.</td></tr>
<tr><td>Plan</td><td>Additional suggestion:
<u>What is the role of Anna?</u></td><td>Make the information meaningful for Anna by considering her prior knowledge.</td><td>Consider the pre-requisite skills and prior knowledge of the learner.</td></tr>
<tr><td>Plan</td><td>Additional suggestion:
<u>Need some structure?</u></td><td><u>(presented in separate window)</u>
Before:
Instructional Purpose:
Define Learning Activities:

During:
Role of Student:
Role of Instructor:

After:
Assessment:</td><td><u>(presented in separate window)</u>
Instructional Goal:
Objective(s):
Materials / Preparation:
Level and Learner Characteristics:
Procedure:
• Motivating students:
• Informing students of objectives:
• Helping students recall prerequisites:
• Presenting info and examples:
• Provide practice and feedback:
• Summarizing the lesson:
Assessment:</td></tr>
<tr><td>Assessment</td><td>Initial observation</td><td>Think of an authentic situation in which Anna and her classmates could demonstrate their skills.</td><td>Here you need to determine whether the goals you set initially are met.</td></tr>
<tr><td>Assessment</td><td>Additional suggestion:
<u>Purpose of assessment</u></td><td>For Anna and her classmates to perform a real-world task to model their learning regarding the subject.</td><td>For Anna and her classmates to demonstrate the knowledge that they learned.</td></tr>
</table>