# The Case for Social Agency in Computer-Based Teaching: Do Students Learn More Deeply When They Interact With Animated Pedagogical Agents?

Roxana Moreno

*Educational Psychology Program*
*University of New Mexico*

Richard E. Mayer

*Department of Psychology*
*University of California, Santa Barbara*

Hiller A. Spires

*Department of Curriculum and Instruction*
*North Carolina State University*

James C. Lester

*Department of Computer Science*
*North Carolina State University*

College students (in Experiment 1) and 7th-grade students (in Experiment 2) learned how to design the roots, stem, and leaves of plants to survive in 8 different environments through a computer-based multimedia lesson. They learned by interacting with an animated pedagogical agent who spoke to them (Group PA) or received identical graphics and explanations as on-screen text without a pedagogical agent (Group No PA). Group PA outperformed Group No PA on transfer tests and interest ratings but not on retention tests. To investigate further the basis for this personal agent effect, we varied the interactivity of the agent-based lesson (Experiment 3) and found an

Requests for reprints should be sent to Roxana Moreno, Educational Psychology Program, University of New Mexico, Albuquerque, NM 87131. E-mail: moreno@unm.edu

interactivity effect: Students who participate in the design of plant parts remember more and transfer what they have learned to solve new problems better than students who learn the same materials without participation. Next, we varied whether the agent's words were presented as speech or on-screen text, and whether the agent's image appeared on the screen. Both with a fictional agent (Experiment 4) and a video of a human face (Experiment 5), students performed better on tests of retention and problem-solving transfer when words were presented as speech rather than on-screen text (producing a modality effect) but visual presence of the agent did not affect test performance (producing no image effect). Results support the introduction of interactive pedagogical agents who communicate with students via speech to promote meaningful learning in multimedia lessons.

For centuries, text has been the major format for teaching scientific material and books have been the major teaching tool. Advances in computer and communication technologies have the potential for improving human learning, but all too often computers are used as high-tech books that present great amounts of information in text form. This project explores a potentially more productive application of educational technology in which an individual learner has the opportunity to develop a social relation with a computer by interacting with an animated pedagogical agent.

The design of computer-based teaching can be driven by the designer's conception of the nature of teaching, which can range from a teaching-as-transmitting view to a teaching-as-communicating view. According to the teaching-as-transmitting view, the role of the teacher is to present information and the role of the learner is to receive it. This classic view has been widely criticized in favor of a teaching-as-communicating view, in which the role of the teacher is to foster the construction of meaningful mental representations in the learner and the role of the learner is to construct mental representations that make sense (Mayer, 1992). For example, the National Science Education Standards (National Research Council, 1995) called for changing emphases in science teaching by putting "less emphasis on … focusing on student acquisition of information" and "more emphasis on … focusing on student understanding and use of scientific knowledge, ideas, and inquiry processes" (p. 52). The goal of this study is to investigate one promising technique for promoting constructivist learning in a computer-based environment—namely, allowing learners to interact with an animated pedagogical agent.

## PROMOTING KNOWLEDGE CONSTRUCTION IN COMPUTER-BASED ENVIRONMENTS

How can we foster the process of knowledge construction in learners using a computer-based environment? This question is most often discussed in cognitive terms—focusing on how to promote cognitive processing in learners that will lead

to appropriate cognitive representations. However, Vygotsky (1978) argued that the teaching process is also an inherently social process involving communication between teacher and learner. One example of this Vygotskian approach is cognitive apprenticeship theory (Collins, Brown, & Newman, 1989). Apprenticeship theory was developed from the observations of natural teaching in homes and communities (Rogoff, 1991; Tharp & Gallimore, 1988; Vygotsky, 1978; Wertsch, 1991). The agent–student interaction parallels Vygotsky's responsive social world in which more capable others play a role in the development of a child's thinking abilities (Vygotsky, 1978). According to this conception, adults often assist children in thinking about problems that they could not do on their own but can do with assistance.

In this study, we focus on the social aspects of a teaching environment that, on the surface, seems devoid of social communication—namely, the case of an individual student sitting at a computer station running educational software. Although it may seem odd to view this situation as an exercise in social communication, our hypothesis is that learning can be enhanced when learners interpret their relation with the computer as a social one involving reciprocal communication. Thus, our major challenge in this research is to create a computer-based environment that learners will interpret as involving a collaborative communication with the computer, although we do not directly measure the degree to which students experience a social relation with the agent.

Consider two situations that teach the same material about the function of plant structures, one intended to prime a social interpretation of the teaching situation in the learner (which we call a *social agency environment*), and one intended to present the same scientific material in a direct way (which we call a *text environment*). The central feature of the social agency environment is an animated pedagogical agent—a likable cartoon figure who talks to the learner and responds to the learner's input. In our study, the major aspects of the social agency environment include (a) presenting a visual image of the agent's body, especially the agent's face; (b) presenting an auditory image of the agent's voice, using speech rather than on-screen text; and (c) allowing the learner to interact with the agent by providing input and receiving a contingent response. These three aspects are intended to help the learner accept his or her relation with the computer as a social one, in which communicating and participating are as natural as possible within the limits of available technology. Our goal is to determine whether techniques aimed at priming a social interpretation in the learner encourage the learner to make a stronger effort to understand the material.

For this purpose, at the first stage of our research program (Experiments 1 and 2), we compared the learning outcomes of students who interacted with an animated pedagogical agent who spoke to them (Group PA) with those of students who received identical explanations as on-screen text without the mediation of a pedagogical agent (Group No PA).

At the second stage of our research program (Experiments 3, 4, and 5), we manipulated particular features of the social agency environment to examine which of its three attributes are most important in the promotion of meaningful learning. In Experiment 3, to determine the role of students' active interaction and participation with the learning environment, we compared the learning outcomes of students who were given the opportunity to design the plant structures (Group P) with those of students who did not actively participate with the agent in the plant design process (Group No P). In Experiments 4 and 5, to determine the role of the pedagogical agent's visual presence in the environment, we compared the learning outcomes of students who were presented with the image of the agent (Groups IT and IN) with those of students not presented with the image of the agent (Groups No IT and No IN). Finally, to determine the role of the modality in which the pedagogical agent communicates with the student, we compared the learning outcomes of students who received explanations in an auditory modality as narration (Groups IN and No IN) with the outcomes of those who received identical explanations in a visual modality as on-screen text (Groups IT and No IT).

## Two Multimedia Learning Scenarios

The learning environment used in this study is a microworld called Design-A-Plant, in which the student travels to an alien planet with certain environmental conditions (e.g., low rainfall, little sunlight) and must design a plant that would flourish there, including design of the characteristics of the leaves, stem, and roots. The Design-A-Plant microworld uses an animated pedagogic agent called Herman, an alien bug with humanlike movements and an amusing voice (Lester et al., 1997; Lester, Stone, & Stelling, 1999). Herman offers individualized advice concerning the relation between plant features and environmental features by providing students with feedback on the choices they make in the process of designing plants. Herman's actions are dynamically selected and assembled by a behavior-sequencing engine that guides the presentation of problem-solving advice to learners. For a set of eight different environmental conditions, Herman has the following functions: (a) He introduces each new environment to the student, (b) he asks the student to design the roots that are appropriate for that environment, (c) he gives feedback on the student's choice of the root, (d) he asks the student to design the stem that is appropriate for the environment, (e) he gives feedback on the student's choice of the stem, (f) he asks the student to design the leaves that are appropriate for the environment, (g) he gives feedback on the student's choice of the leaves, and (h) he takes the student to a new environment. The feedback for each choice consists of a verbal explanation in the form of narration. For each of the choices of root, stem, and leaves, students are presented with the corresponding library of plant parts' graphics and names. They then are asked to click on one of the possible options to design their plant.

Figure 1 shows selected frames from the third example problem presented to the PA group. In the first frame, Herman introduces the student to the new environmental conditions for the planet. Herman's image appears on the bottom left corner of the screen as he says: "Hmm, this place feels strong in the force. Now, let's make it strong in plant life as well. The high rain and low sunlight make the leaf and stem choices important. However, it does look like any root will work just fine." In the second frame, the eight possible root types are displayed on the computer screen while Herman waits for the student's choice of the correct root. In the third frame, Herman appears on the screen and gives the following explanation after the student has chosen a stem for the environment: "Mmm, a short stem here in this shade is dangerous for the plant, because its leaves won't get any sunlight. Make sure the stem is long enough to put the leaves in the sun." In the fourth frame, if students fail in their choice, Herman instructs them to "choose a long stem." The Design-A-Plant program is intended to help students appreciate the relation between structure and function in plants, but is not intended to teach evolutionary theory in depth.

In contrast, the same information can be presented more directly through a text-based environment. In this environment there is no animated pedagogical agent, but every instructional word that the agent says in the social agency environment is presented as on-screen text. In addition, every picture presented in the social agency environment is also presented in the text-based environment. The learner sees the same set of example plants (presented as step-by-step worked-out examples) and receives the same instructional words (presented as on-screen text) as in the social agency environment. In contrast to the three aspects of social agency, students in the text-based version do not see the agent's visual image, do not hear the agent's voice, and are not able to interact with an agent by designing the plant before listening to the explanations.

Figure 2 shows selected frames from the third example problem presented to the No PA group. In the first frame, the student is introduced to the new environmental conditions for the planet. A text box in the upper middle portion of the screen reads: "In this environment, the heavy rain and low sunlight make the choice of leaf and stem important. However, it looks like any root will work just fine." In the second frame, as in the PA version, the eight possible root types are displayed to the student on the computer screen while the text box displays this text: "There are eight kinds of roots." However, whereas in the PA version the program pauses until the student makes a choice, in the No PA version the program pauses until the student clicks on the Continue button. In the third frame, the student is given the following explanation for choosing an appropriate stem for the environment: "A short stem here in the shade is dangerous for the plant because the leaves won't get any sunlight. The stem needs to be long enough to put the leaves in the sun." In the fourth frame, the student is shown the correct stems for the environment while the text box displays this: "For this environment, the plant should have a long stem."

**Frame 1**

**Frame 2**

**Frame 3**

**Frame 4**

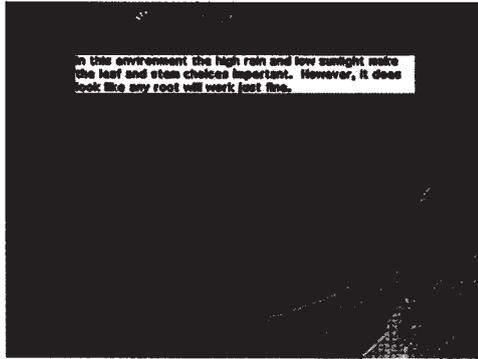FIGURE 1    Selected frames from the PA program—Experiments 1 and 2.

## The Case for Social Agency

The social agency environment includes an element of discovery, unlike the text-based environment. Discovery-based learning environments are intended to facilitate constructivist learning through creative problem-solving experiences. However, the characteristics of discovery-based environments that offer the greatest potential for fostering learning also pose the greatest challenge: The complexity of the learning experience, based on the learner's freedom to explore and design artifacts in microworlds, constantly threatens to overwhelm the learner. To combat this complexity, we created a guided discovery learning environment that provides scaffolding in the form of highly contextualized problem-solving advice that is customized for each learner. Perhaps the most intriguing vehicle for providing such dynamically individualized scaffolding is the emerging technology of animated pedagogical agents—lifelike on-screen characters who provide contextualized advice and feedback throughout a learning episode (Bates, 1994; Lester et al., 1997; Lester et al., 1999). Thus, animated pedagogical agents represent a special class of software agents (Bradshaw, 1997; Genesereth & Ketchpel, 1994; Laurel, 1990; Maes, 1991; Reeves & Nass, 1996). Animated pedagogical agents allow for the inclusion of feedback in computer-based learning that goes beyond traditional programmed instruction because the agent appears to act as personal tutor.
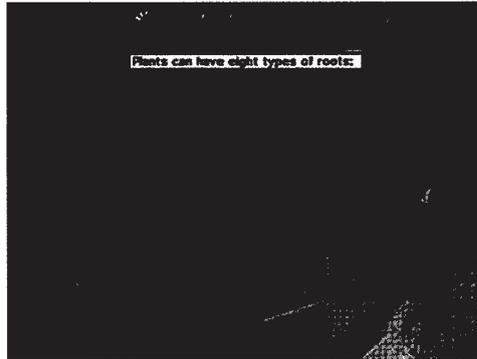
The goal of this study is to test the hypothesis that animated pedagogical agents can promote constructivist learning in a guided, discovery-based learning environment. Constructivist learning is defined as meaningful learning in which a learner actively builds a mental model of the system they are to learn, and is best evaluated by problem-solving transfer in which the learner must use what has been learned to solve challenging new problems (Mayer, 1997; Mayer & Wittrock, 1996).

Does learning with an animated pedagogical agent in a guided discovery environment promote constructivist learning? To help answer this question, we compared the learning outcomes of students who learned about environmental science in the Design-A-Plant microworld (the PA group) with the learning outcomes of students who received the identical verbal material in a computer-based text environment (the No PA group). The two environments used the same words, although the words were spoken by Herman for the PA group and were presented as on-screen text for the No PA group. Personal comments reflecting only Herman's likable personality, such as "Wow" or "Yippee," were eliminated from the text version. The same graphics were used in both groups with the exception that Herman's image was deleted for the No PA group. We focused on three important measures of learning: retention (in which we assessed memory for the basic factual information that was presented), problem-solving transfer (in which we asked students to solve new problems based on the principles learned in the Design-A-Plant environment), and interest (in which we asked students to rate how interesting the material was).
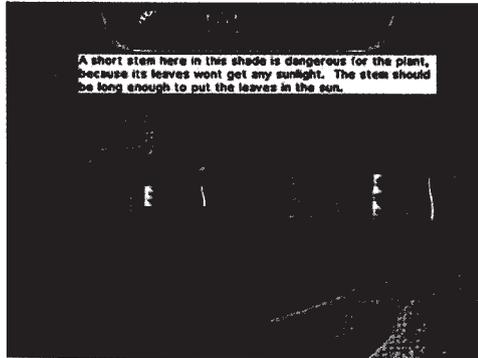
**Frame 1**

In this environment the high rain and low sunlight make the leaf and stem choices important. However, it does look like any root will work just fine.

**Frame 2**

Plants can have eight types of roots:

**Frame 3**

A short stem here in this shade is dangerous for the plant, because its leaves wont get any sunlight. The stem should be long enough to put the leaves in the sun.

**Frame 4**

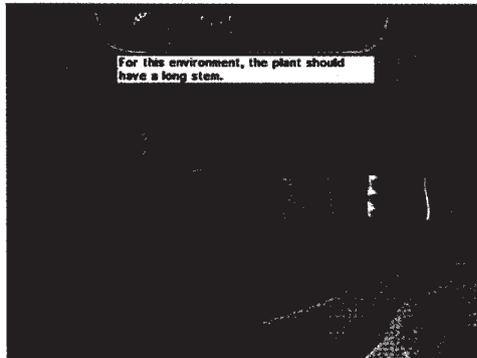For this environment, the plant should have a long stem.

FIGURE 2   Selected frames from the No PA program—Experiments 1 and 2.

How do agents affect student learning? Reeves and Nass (1996) provided convincing evidence that students view their contact with computer-based characters as social interaction subject to the same social rules as interaction with humans. These social rules include students liking and deeply attending to computer-based characters (e.g., Herman the bug in the Design-A-Plant program) as well as real people who interact with them. Perhaps the most striking finding in Reeves and Nass's research program concerned the ease with which computer users viewed their interactions with computer-mediated characters as social interactions. According to Reeves and Nass, computer-based characters do not have to be realistic to prime social interaction rules, so that a color line drawing or a happy voice may be all that is needed. Herman the bug seems to exceed Reeves and Nass' minimal criteria for priming social interaction rules in students.

## Constructivist and Interference Theories of Social Agency

In this section, we consider two possible cognitive consequences of our PA treatment: the constructivist hypothesis and the interference hypothesis. The *constructivist hypothesis* holds that the treatment promotes increased effort at sense-making by learners. The *interference hypothesis* holds that the treatment may distract or overload the learner.

The constructivist view has its roots in interest theories of motivation (Dewey, 1913; Harp & Mayer, 1998; Renninger, Hidi, & Krapp, 1992), which propose that students work harder to make sense of presented material and therefore learn more deeply when they are personally interested in the learning task than when they are not. Reeves and Nass's (1996) research on computer-based characters was consistent with interest theories of academic motivation. Animated pedagogical agents may personalize the learning task and help students feel an emotional connection with the agent. This feeling of a positive personal relationship promotes interest in the learning task, which in turn fosters constructivist learning (Bates, 1994; Lester et al., 1997). When students identify with likable characters who seem personally involved in their learning, they are more likely to enjoy the learning situation and want to understand the material. When students try hard to make sense of the presented material, they form a coherent mental model that enables them to apply what they learned to challenging new problem-solving situations (Mayer & Wittrock, 1996). If animated pedagogical agents promote constructivist learning, then we predict that the PA group will perform better than the No PA group on measures of problem-solving transfer and interest; however, predictions about retention are not clear.

The interference view is also related to early theories of academic interest dating back to Dewey's (1913) admonition against viewing interest as extra frills that can be added to an otherwise boring lesson. Recent research has re-

vealed that adding entertaining but irrelevant sentences (which can be called *seductive details*) to a text either does not help or actually hurts students' retention of the core material (Garner, Gillingham, & White, 1989; Renninger et al., 1992). More recent research has shown that adding entertaining illustrations and text to a scientific explanation actually hurts students' retention and transfer of the core material (Harp & Mayer, 1998). Similar results were found for the inclusion of irrelevant auditory material in the form of music and sounds that hindered students' recall and understanding of a multimedia explanation (Moreno & Mayer, 2000). In sum, research on seductive details has supported interference theory. Students achieve better transfer and retention when extraneous materials are excluded rather than included in a lesson (Mayer, 2001; Moreno & Mayer, 2000).

This study extends earlier work on seductive details by examining the effects of adding an animated pedagogic agent within a computer-based learning environment. According to interference theory, and congruent with research on seductive details, any additional material that is not necessary to make the lesson intelligible reduces effective working-memory capacity and thereby interferes with the learning of the core material. In this case, less of the core material—such as the narration describing how to design a plant for a given environment—is selected for further processing. The result is poorer performance on a retention test. In addition, learners have less capacity left for building coherent verbal and visual representations and for connecting them with each other, as part of the students' cognitive resources are used in processing the behavior of the animated agent. The result is poorer performance on a transfer test. However, predictions about ratings of interest are not clear. In short, animated pedagogical agents may serve as entertaining but irrelevant features of the lesson that interfere with the student's ability to make sense of what is presented (Harp & Mayer, 1998; Moreno & Mayer, 2000). Given the constraints on the learner's working memories, interference theory predicts that presenting an animated agent will result in lower performance on measures of retention and transfer for the PA group as compared to the No PA group.

In summary, the constructivist and interference views of agents make conflicting predictions concerning the effects of social agency on retention, transfer, and interest. The constructivist view assumes that social agency has the same kind of effect as cognitively interesting adjuncts such as summaries, explanatory illustrations, and text cohesiveness that have been shown to promote understanding (Mayer, Bove, Bryman, Mars, & Tapangco, 1996). In contrast, the interference view assumes that social agency has the same kind of effect as emotionally interesting adjuncts, such as seductive details, which appear to only promote affective arousal in the reader and interfere with understanding (Kintsch, 1980).

## EXPERIMENT 1

The purpose of Experiment 1 was to determine whether providing a social agency environment in which students interact with an animated pedagogical agent results in deeper learning than providing the same information as an on-screen text environment. We define *deeper learning* as students' ability to use what they have learned to build a mental model of the scientific system and apply it to solve new problems (Mayer, 1997). To what extent do pedagogical agents help students' learning? Recall and comprehension indicate two different levels of processing of the instructional materials (Elliot, McGregor, & Gable, 1999), with recall indicating surface processing or rote memorization of information (Zimmerman & Pons, 1986) and comprehension indicating deep processing or integration of the new information with prior knowledge and experience (Weinstein & Mayer, 1986). We therefore concentrate on two learning measures: retention of the factual information presented during the computer lesson (which indicates a shallower level of processing) and use of the concepts learned during the computer lesson to solve new problems (which indicates a deeper level of processing).

### Method

*Participants and design.*    The participants were 44 college students from the Psychology Subject Pool at the University of California, Santa Barbara. Twenty-four participants served in the No PA group and 20 participants served in the PA group.

*Materials and apparatus.*    For each participant, the paper-and-pencil materials consisted of a participant questionnaire, a retention test, a seven-page problem-solving test, and a program-rating sheet. The participant questionnaire solicited information concerning the participant's name, grades, Scholastic Assessment Test scores, gender, and botany knowledge.

The retention test consisted of the following three questions, each typed on the same sheet:

1. Please write down all the types of roots that you can remember from the lesson.
2. Please write down all the types of stems that you can remember from the lesson.
3. Please write down all the types of leaves that you can remember from the lesson.

The problem-solving test consisted of seven questions, each typed on a separate sheet. As shown in Figure 3, in the first five questions the student had to check at

least one of the possible kinds of roots, stems, and leaves from a list containing all possible options. After checking the right plant parts, the student was asked to write an explanation of the choices. The five problem-solving sheets were labeled with the following instructions:

1. Design a plant to live in an environment that has low sunlight.
2. Design a plant to live in an environment that has low temperature and a high water table.
3. Design a plant to live in an environment that has high temperature.
4. Design a plant to live in an environment that has heavy rainfall and low nutrients.
5. Design a plant to live in an environment that has high wind.

The final two problems each asked the following question: "In what kind of environment would you expect to see the following plant flourish (i.e., to see the plant grow well)? Please put a check mark next to one or more conditions." Following the question, a diagram of a different plant for each problem was presented on the middle of the sheet and a list with the eight possible environmental conditions was provided under the diagram (i.e., low temperature, high temperature, low rainfall, heavy rainfall, low nutrients, high nutrients, low water table, and high water table). Problem 6 consisted of a plant with thick, large, and thin-skinned leaves; short, thick, and no-bark stem; and branching, shallow, and thin roots. Problem 7 consisted of a plant with thick, small, thick-skinned leaves; thick, long, and bark stem; and nonbranching, deep, and thick roots. Finally, the following question appeared at the bottom of the sheet for each of these two problems: "Why do you think that the plant designed will flourish in the environment that you chose?"

Problems 1, 3, and 7 were classified as easy and Problems 2, 4, 5, and 6 as difficult. Problems 1 and 3 were classified as easy because they only included one environmental condition (low sunlight and high temperature, respectively). Problem 7 was classified as easy because the plant depicted in the diagram was identical to one of the example problems in the multimedia lesson. Problems 2 and 4 were classified as difficult because they included more than one environmental condition (low temperature and high water table, and heavy rainfall and low nutrients, respectively). Problem 5 was classified as difficult because it included an environmental condition not studied during the multimedia lesson (wind). Problem 6 was classified as difficult because the plant depicted in the diagram was not an example from the multimedia lesson.

The program-rating sheet contained seven questions asking participants to rate on 10-point scales their level of motivation, interest, understanding, and the perceived difficulty of the material. The following two questions were intended to assess the learner's interest level: "How interesting is this material?" ranging from 1 (*boring*) to 10 (*interesting*) and "How entertaining is this material?" ranging from

NAME _____

Design a plant to live in an environment that has low sunlight.

Circle the types of roots (1 or more ):

| | Branching | | | | Non-Branching | | |
|---|---|---|---|---|---|---|---|
| Deep | Deep | Shallow | Shallow | Deep | Deep | Shallow | Shallow |
| Thick | Thin | Thick | Thin | Thick | Thin | Thick | Thin |

Circle the types of stem (1 or more ):

| | Short | | | | Long | | |
|---|---|---|---|---|---|---|---|
| Thick, | Thin, | Thick, | Thin, | Thick, | Thin, | Thick, | Thin, |
| Bark | Bark | No Bark | No Bark | Bark | Bark | No Bark | No Bark |

Circle the types of leaves (1 or more ):

| | Thin | | | | Thick | | |
|---|---|---|---|---|---|---|---|
| Small, | Small, | Large, | Large, | Small, | Small, | Large, | Large, |
| Thick skin | Thin skin | Thin skin | Thick skin | Thick skin | Thin skin | Thin skin | Thick skin |

Why do you think that the plant you designed will survive in this environment?
(You can use the back of the sheet to write your answer).

FIGURE 3    A transfer problem.

1 (*tiresome*) to 10 (*entertaining*). The following question was intended to assess the learner's motivation level: "If you had a chance to use this program with new environmental conditions, how eager would you be to do so?" ranging from 1 (*not eager*) to 10 (*very eager*). The following two questions were intended to assess the learner's level of understanding: "How much does this material help you understand the relation between plant design and the environment?" ranging from 1 (*not*

*at all*) to 10 (*very much*) and "How helpful is this material for learning about plant design?" ranging from 1 (*unhelpful*) to 10 (*helpful*). The following two questions were intended to assess the learner's perception of learning difficulty: "How difficult was the material?" ranging from 1 (*easy*) to 10 (*difficult*) and "How much effort is required to learn the material?" ranging from 1 (*little*) to 10 (*much*).

The computerized materials consisted of two multimedia computer programs on how to design a plant. The PA version was a multimedia program called Design-A-Plant developed by the IntelliMedia Initiative at the College of Engineering of North Carolina State University (Lester et al., 1997; Lester et al., 1999). It includes a lifelike pedagogic agent, Herman, a bug who provides advice to learners as they graphically assemble plants from a library of plant structures such as roots, stems, and leaves for eight different environments. The No PA version contained the same visual and verbal materials presented in the PA version, but the agent, Herman, was deleted. It included the same graphics representing the environments and plant structures. It also contained the same verbal material presented in the PA version, but instead of narration, it provided text. Personal comments used in the PA version, such as "Wow" or "Yippee," were deleted from the text. Students in the No PA version navigated through the same environmental conditions and observed the same library of plant structures as students in the PA version, but did not have the opportunity to assemble the plants from the library. Instead of clicking on the plant parts to assemble, students in the No PA version needed to click on the Continue button located at the bottom of the computer screen to listen to the respective plant part explanation. The multimedia animations were developed using Director 4.04 (Macromedia, 1995). Examples of frames from the PA and No PA programs are presented in Figures 1 and 2, respectively.

The apparatus consisted of five Macintosh IIci computer systems with 14-in. monitors and Sony headphones.

*Procedure.*    Participants were tested in groups of 1 to 3 per session. Each participant was randomly assigned to a treatment group (PA or No PA) and was seated at an individual cubicle in front of a computer. First, participants completed the participant questionnaire at their own rate. Next, the experimenter presented oral instructions stating that the computer program would teach them how plants should be designed to survive in different environments, and that when the computer program was finished, the experimenter would have some questions for the participants to answer. Students were told to remain quietly seated once the multimedia lesson was over until the experimenter gave them further instructions. Participants in the PA group were told to put on headphones, and all participants were instructed to press the spacebar to begin the program. On pressing the spacebar, the respective version of the multimedia program was presented once to all participants. All par-

ticipants visited eight different environments. The self-paced visits had a total dura-
tion ranging between 24 min and 28 min. When the program was finished, the ex-
perimenter presented oral instructions for the test, stating that there would be a
series of question sheets and that the participant should keep working until told to
stop. The retention sheet was then distributed. After 5 min, the sheet was collected.
Then, the seven problem-solving sheets were presented one at a time for 3 min
each, with each sheet collected by the experimenter before the subsequent sheet
was handed out. Finally, the program rating sheet was presented and collected after
3 min.

   A scorer not aware of the treatment condition of each participant determined
the retention, transfer, and program-rating scores for each participant. A reten-
tion score was computed for each participant by counting the number of correct
categories (out of a possible nine) for each plant part (root, stem, and leaf) that
the participant produced on the retention test. The total transfer score was com-
puted for each participant by counting the number of acceptable answers that the
participant produced across the seven transfer problems. For each of the first
five questions, 1 point was given by counting the number of correct categories
that the participant circled for each plant part, and 1 point was given for each
correctly stated explanation about their choice of category of plant type, regard-
less of wording. For example, for the second transfer question, which asked the
student to "Design a plant to live in an environment that has low temperature
and high water table," eight plant categories (branching roots, deep roots, thick
roots, thick stem, bark stem, thick leaves, small leaves, and thick-skinned
leaves) had to be checked and the student could obtain a maximum possible
score of 16 (8 points for each correct category, plus 8 points for each correct ex-
planation corresponding to the categories checked). For each of the last two
questions, 1 point was given for each correct environment condition chosen by
the participant (out of four), and 1 point was given for each correctly stated ex-
planation about their choice of type of environment, regardless of wording. The
easy transfer score was computed for each participant by adding the number of
acceptable answers that the participant produced for Questions 1, 3, and 7. The
difficult transfer score was computed for each participant by adding the number
of acceptable answers that the participant produced for Questions 2, 4, 5, and 6.
Mean ratings on the program-rating sheet were computed for motivation, inter-
est, understanding, and perceived difficulty.

## Results and Discussion

We determined whether the PA and No PA groups differed on measures of reten-
tion, transfer, and interest. The top lines of Table 1 present the means and standard
deviations for the two groups on each of these measures.

TABLE 1
Mean Score on Retention, Transfer, and Interest Tests, and Corresponding Standard
Deviations for Two Groups in Experiments 1 and 2

| | | | Type of Test | | | |
| | Retention | | Transfer | | Interest | |
| Group | M | SD | M | SD | M | SD |
|---|---|---|---|---|---|---|
| Experiment 1 | | | | | | |
| PA | 8.20 | 1.15 | 35.35 | 5.92 | 6.50 | 1.96 |
| No PA | 7.29 | 1.94 | 28.63 | 7.08 | 4.56 | 2.27 |
| Experiment 2 | | | | | | |
| PA | 5.91 | 1.81 | 23.23 | 9.17 | 7.52 | 1.83 |
| No PA | 5.68 | 2.19 | 15.71 | 6.29 | 5.54 | 2.53 |

*Note.* Scores ranged from 0 to 9 for the retention test, from 0 to 60 for the transfer test, and from 1 to 10 for the interest scores. PA = pedagogical agent.

*Effects on retention: Did students who learned interactively with a pedagogical agent retain more of the presented information than students who learned in a conventional environment?* As a retention test, we simply asked students to name as many types of roots, stems, and leaves as they could (highly relevant information that was prominently displayed in both instructional programs). The main prediction arising from the constructivist hypothesis was that students who learn with the help of a pedagogical agent will outperform those who learn in a more traditional text and graphics environment on tests of problem-solving transfer, especially for hard problems. However, we included tests of retention to investigate whether personal agents might also help students remember the factual information presented in the computer lesson.

The mean number of items correctly recalled by the PA group ($M = 8.20$, $SD = 1.15$) was not significantly different from the mean number of items correctly recalled by the No PA group ($M = 7.29$, $SD = 1.94$), based on a two-tailed $t$ test, $t(42) = 1.83$, $p = ns$. The results suggest that students who learn with an animated pedagogical agent in a discovery environment do not differ in their retention of the basic factual information from students who learn the same material with on-screen text.

*Effects on transfer: Were students who learned interactively with a pedagogical agent more able to apply what they learned to solve new problems than students who learned in a conventional environment?* The major prediction in this study was that students in the PA group would learn more deeply than No PA students; thus, we predicted that the PA group would outperform the No PA group on tests of problem-solving transfer in which they were required to

apply what they learned to solve new problems. As predicted, students in the PA group produced significantly more correct solutions on transfer problems ($M = 35.35$, $SD = 5.92$) than students in the No PA group ($M = 28.63$, $SD = 7.08$), based on a two-tailed $t$ test, $t(42) = 3.38$, $p < .005$.

Because difficult problems require more cognitive effort than easy problems, we expected the differences to be particularly strong for difficult problems. Consistent with this prediction, students in the PA group produced significantly more correct solutions on difficult transfer problems ($M = 25.45$, $SD = 4.38$) than students in the No PA group ($M = 18.83$, $SD = 4.44$), based on a two-tailed $t$ test, $t(42) = 8.88$, $p < .001$. The mean number of correct solutions on easy problems produced by the PA group ($M = 9.90$, $SD = 2.88$) did not differ significantly from the corresponding score of the No PA group ($M = 9.79$, $SD = 3.32$), based on a two-tailed $t$ test, $t(42) < 1$, $p = ns$.

The results are consistent with interest theories of motivation (Dewey, 1913; Harp & Mayer, 1998; Renninger et al., 1992), in which animated pedagogical agents may personalize the learning task and help students feel a positive personal relationship with the agent, promoting interest in the learning task and fostering constructivist learning (Bates, 1994; Lester et al., 1997). More motivated students try harder to make sense of the presented material than do less motivated students. They are also more likely to form a coherent mental model that enables them to apply what they learned to challenging new problem-solving situations. This may have been the case for the difficult problems, in which students in the PA group outperformed students in the No PA group.

*Effects on interest: Did students who learned interactively with a pedagogical agent like the task more than students who learned in a conventional environment?*     The foregoing results are consistent with the idea that students who learn with animated pedagogic agents work harder to make sense of the material than do students who learn in a more conventional text-based environment. We also tested this idea by assessing students' interest in learning the material, predicting that the PA group would indicate higher interest than the No PA group. As predicted, the PA group rated their interest in the material ($M = 6.50$, $SD = 1.96$) significantly greater than did the No PA group ($M = 4.56$, $SD = 2.27$), based on a two-tailed $t$ test, $t(42) = 2.99$, $p < .01$.

The rest of the program-rating questionnaire tapped other aspects of the learning experience. As with the results involving interest, students in the PA group indicated stronger interest in continuing to use the program ($M = 5.90$, $SD = 2.00$) than did students in the No PA group ($M = 4.42$, $SD = 2.47$), based on a two-tailed $t$ test, $t(42) = 2.21$, $p < .05$. The groups did not differ, however, on their cognitive assessments of how understandable or how difficult the material was: for ratings of understandability, $M = 7.55$ ($SD = 2.11$) for the PA group and $M = 8.19$ ($SD = 1.32$)

for the No PA group, $t(42) = 1.22$, $p = ns$; for ratings of difficulty, $M = 5.00$ ($SD = 1.79$) for the PA group and $M = 4.67$ ($SD = 1.76$) for the No PA group, $t(42) < 1$, $p = ns$. In short, program ratings of affect revealed that students in the PA group were significantly more interested in the material and were significantly more eager to interact with the program again. The novelty of the PA treatment may contribute to its interest. The results are consistent with interest theories of motivation (Dewey, 1913; Harp & Mayer, 1998; Renninger et al., 1992), in which students work harder to make sense of presented material and therefore learn more deeply when they are personally interested in the learning task than when they are not.

## EXPERIMENT 2

The results of Experiment 1 are consistent with a constructivist theory of social agency, suggesting that learning with pedagogical agents can encourage students to learn more deeply. The purpose of Experiment 2 was to determine whether the pattern of results obtained in Experiment 1 with college students could be replicated in another study involving younger learners.

## Method

*Participants and design.*    The participants were 48 seventh-grade students from an urban middle school in the southeastern part of the United States. Twenty-four students served in the pedagogical agent (PA) group and 24 students in the no pedagogical agent (No PA) group. The students came from a two-teacher classroom block of language arts and science with all students participating unless parental permission was denied ($n = 1$). There were 26 boys and 22 girls with similar distributions of boys and girls in both groups. The majority of students (84%) reported speaking English as their native language, but 16% reported other native languages, including Vietnamese, Persian, Spanish, Arabic, and Urdu. The distribution of language-minority students was similar in both treatment groups. On a questionnaire administered before the study, 54% of the students reported little prior knowledge about botany, 44% reported average prior knowledge, and 2% reported much prior knowledge. Concerning interest in botany, 17% reported little interest, 77% reported average interest, and 6% reported much interest. The two treatment groups were nearly identical in their average ratings of experience and of interest.

*Materials.*    The materials were essentially identical to those used in Experiment 1. The apparatus consisted of four Apple Macintosh computer systems with color monitors.

*Procedure.*     Participants were randomly assigned to treatment groups (i.e., PA or No PA) and were tested in groups of up to 4 per session. Students were seated at tables, each with their own individual computer, specifically set up for the experiment in a corner of the school library. Each 90-min session was divided into three segments. First, the experimenter presented oral instructions explaining the purpose of the Design-A-Plant program. At this point, students learned that the computer program would teach them how plants should be designed to survive in eight different environments. Students then individually completed the participant questionnaire at their own rates. Next, students worked at their own pace (ranging up to 40 min) with their respective version of the software. The experimenter then passed out the tests, explained their format, and instructed the students to continue working until they were told to stop. The order and timing of the problems was the same as in Experiment 1, with students answering the test questions within a 35-min time limit. Finally, the program-rating questionnaire was administered as in Experiment 1, and students responded within a 3-min time limit.

The scoring procedure was identical to Experiment 1.

## Results and Discussion

The results were analyzed as in Experiment 1 to determine whether the PA and No PA groups differed on measures of retention, transfer, and interest. Due to clerical errors in experiment administration, the retention test was not administered to 3 participants (1 in the PA group and 2 in the No PA group) and part of the transfer test was not administered to 2 participants (both in the PA group). These data were therefore not included in the analyses. The bottom portion of Table 1 presents the means and standard deviations of the scores produced by the two groups on the three measures.

*Effects on retention: Did students who learned interactively with a pedagogical agent retain more of the presented information than students who learned in a conventional environment?*     As in Experiment 1, both groups were exposed to identical factual information presented using the same words and pictures. When asked to remember highly relevant information that was prominently displayed in both instructional programs, the mean number of items correctly recalled by the PA group ($M = 5.91$, $SD = 1.81$) did not differ significantly from the mean number of items correctly recalled by the No PA group ($M = 5.68$, $SD = 2.19$), $t(43) = .39$, $p = ns$.

*Effects on transfer: Were students who learned interactively with a pedagogical agent more able to apply what they learned to solve new problems than students who learned in a conventional environment?*     Our main prediction was that the PA group would be better able than the No PA group

to apply what they learned to solve new problems. As predicted, students in the PA group produced significantly more correct answers on the transfer test ($M$ = 23.23, $SD$ = 9.17) than did students in the No PA group ($M$ = 15.71, $SD$ = 6.29), $t(44)$ = 3.27, $p$ < .005.

As in Experiment 1, students in the PA group produced significantly more correct answers on the difficult transfer problems ($M$ = 17.17, $SD$ = 6.81) than did students in the No PA group ($M$ = 11.29, $SD$ = 4.39), $t(46)$ = 3.55, $p$ < .001. The difference reached only marginal significance on easy transfer problems ($M$ = 5.77, $SD$ = 4.42 for the PA group; $M$ = 4.42, $SD$ = 2.55 for the No PA group), $t(44)$ = 1.79, $p$ = .08. The results replicate those of Experiment 1 and are consistent with the idea that being able to interact with a pedagogical agent helps students to learn more deeply.

*Effects on interest: Did students who learned interactively with a pedagogical agent like the task more than students who learned in a conventional environment?*    As in Experiment 1, students in the PA group rated their enjoyment of the learning task more highly ($M$ = 7.52, $SD$ = 1.83) than did students in the No PA group ($M$ = 5.54, $SD$ = 2.53), $t(46)$ = 3.11, $p$ < .005.

Also as in Experiment 1, the groups did not differ on their cognitive assessments of how understandable or how difficult the material was: For ratings of understandability, $M$ = 8.17 ($SD$ = 1.83) for the PA group and $M$ = 8.69 ($SD$ = 1.39) for the No PA group, $t(46)$ = 1.11, $p$ = $ns;$ for ratings of difficulty, $M$ = 5.8 ($SD$ = 2.10) for the PA group and $M$ = 4.98 ($SD$ = 2.45) for the No PA group, $t(46)$ = 1.32, $p$ = $ns.$ Unlike the students in Experiment 1, the groups did not differ in their motivation to continue working on the program: $M$ = 6.88 ($SD$ = 2.97) for Group PA and $M$ = 6.62 ($SD$ = 2.84) for Group No PA, $t(46)$ = 0.30, $p$ = $ns,$ reflecting a relatively high desire to continue working on the program for both groups. One explanation for the difference in the pattern of motivation ratings in the two experiments is that playing the Design-A-Plant game represented a welcome break from regular schoolwork for both groups in Experiment 2 but not in Experiment 1.

Overall, the results of Experiment 2 replicate those of Experiment 1 with a sample of seventh-graders. Together, the two studies provide consistent evidence across two different learner populations: Students who learn with an animated pedagogical agent do not necessarily acquire more information, but they do learn more deeply than students who learn in a more conventional text-based environment. The findings of Experiments 1 and 2 provide preliminary evidence in favor of using pedagogical agents as software mentors and demonstrate a personal agent effect in multimedia learning environments. Students are more motivated and more interested, and they achieve better transfer, when a computer-based lesson is presented in a social agency environment rather than in an on-screen text environment.

## EXPERIMENT 3

Although it is tempting to conclude that the use of a pedagogical agent was the cause of students' deeper understanding, it is necessary to examine the social agency attributes that might have concurrently accounted for the enhanced learning. First, students' active interaction and participation might have played an important role in learning by engaging students in the elaboration of the materials (Anderson & Pearson, 1984; Doctorow, Wittrock, & Marks, 1978). Second, the agent's image might have acted as a factor in promoting students' engagement or motivation (Dewey, 1913; Weiner, 1990). Third, the agent's voice might have produced more effective processing of the verbal materials than the visually presented on-screen text (Moreno & Mayer, 1999). The following set of experiments investigated the respective roles that these factors might have played in the personal agent effect found in Experiments 1 and 2.

Experiment 3 tested the hypothesis that the main attribute promoting meaningful learning in an agent-based lesson is students' active interaction and participation in the learning environment. The goal was to determine whether the effects we obtained in Experiments 1 and 2 can be attributed mainly to the difference in the level of interactivity between treatment groups. In the PA conditions, the material was explained to students only after they were given the opportunity to design the plant on their own, but in the No PA condition the material was explained directly. By allowing students to select answers before the explanations are provided, tutors allow them to learn by doing (Anzai & Simon, 1979). According to Anderson (1983), a central part of the learning process occurs when students attempt to apply instructional material to solve problems for themselves. Experiment 3 compares an agent-based computer lesson in which students are able to participate in the process of knowledge construction by designing a plant for each environment before listening to the agent's explanations (Group P) with an identical lesson in which students are not able to design plants during the interaction but rather listen to the agent's explanation directly (Group No P).

### Method

*Participants and design.*    The participants were 38 college students recruited from the Psychology Subject Pool at the University of California, Santa Barbara. There were 18 participants in the participation group (Group P) and 20 participants in the no participation group (Group No P). Comparisons were made between the two groups on measures of retention, transfer, and program ratings.

*Materials and apparatus.*    The materials included the same participant questionnaire, retention and transfer tests, and program-rating sheet that were used in Experiment 1.

The computerized materials consisted of two multimedia computer programs on how to design a plant. The P version was identical to the PA versions used for Experiment 1, with two exceptions. First, Herman's voice was replaced by the voice of a drama student in the Arts Department at the University of California, Santa Barbara. Second, Herman's animated image was deleted from the computer program. The No P version was identical to the P version with one exception: Students in the P and No P groups had the same interaction as students in the PA and No PA groups in Experiment 1, respectively. After being introduced to each environment, students in the P group could click on a plant part to design a plant before listening to the agent's explanation, whereas students in the No P group could look at the same plant library for as long as they needed and then click the Continue button situated on the bottom of the screen to listen to the same explanation. As for Experiment 1, both versions were programmed to have the same duration.

*Procedure.*    The procedure was the same as in Experiment 1.

*Scoring.*    A scorer not aware of the treatment condition of each participant determined the retention, transfer, and program-rating scores for each participant in the same fashion as for Experiment 1.

## Results and Discussion

Table 2 shows the mean scores and standard deviations for the P and No P groups on measures of retention, transfer, and interest ratings.

*Issue 1: Did students who participated in the design of plant parts retain more of the presented information than students who learned in the same agency environment with no participation?*    Students in the P and No P groups were exposed to identical factual information presented using identical words and pictures. When asked to remember this information, the mean number of items correctly recalled by the P group ($M = 7.90$, $SD = 0.97$) was significantly larger than the mean number of items correctly recalled by the No P group ($M = 6.78$, $SD = 1.63$), $t(36) = 2.61$, $p = .01$.

*Issue 2: Were students who participated in the design of plant parts more able to apply what they learned to solve new problems than students who learned in the same agency environment with no participation?*    Although our main prediction for Experiment 3 was that the P group would be better able than the No P group to apply what they have learned to solve new problems, students in the P group produced only marginally more correct answers on the transfer test ($M = 38.55$, $SD = 8.10$) than did students in the No P group ($M = 33.61$, $SD = 8.33$), $t(36) = 1.85$, $p = .07$.

TABLE 2
Mean Score on Retention, Transfer, and Interest Tests, and Corresponding Standard
Deviations for Two Groups in Experiment 3

| | Type of Test | | | | | |
| | Retention | | Transfer | | Interest | |
| Group | M | SD | M | SD | M | SD |
|---|---|---|---|---|---|---|
| P | 7.90 | 0.97 | 38.55 | 5.9 | 5.08 | 1.96 |
| No P | 6.78 | 1.63 | 33.61 | 7.1 | 4.53 | 2.43 |

*Note.*  Scores ranged from 0 to 9 for the retention test, from 0 to 60 for the transfer test, and from 5 to 50 for the program-rating scores. P = participation.

However, as in our prior experiments in which the constructivist hypothesis predicted particularly strong differences between groups for difficult transfer problems, students in the P group produced significantly more correct answers on the difficult transfer problems ($M = 27.00, SD = 6.86$) than did the No P group ($M = 22.44, SD = 6.48$), $t(36) = 2.10, p = .04$. There were no significant differences between groups on easy transfer problems ($M = 11.55, SD = 2.69$ for the P group; $M = 11.17, SD = 3.05$ for the No P group), $t(36) = .41, p = ns$. The results are consistent with the findings from Experiments 1 and 2 and lend support to the hypothesis that a contributing factor to students' meaningful learning from a social agency environment resides in their ability to interact with the pedagogical agent.

*Issue 3: Did students who participated in the design of plant parts like the task more than students who learned in the same agency environment with no participation?*    The groups did not differ on either the emotional or cognitive assessments of the program: For ratings of understandability, $M = 7.58$ ($SD = 1.61$) for the P group and $M = 7.53$ ($SD = 2.08$) for the No P group, $t(36) = .08, p = ns;$ for ratings of difficulty, $M = 4.08$ ($SD = 1.57$) for the P group and $M = 3.81$ ($SD = 1.34$) for the No P group, $t(36) = .57, p = ns;$ for ratings of motivation, $M = 4.55$ ($SD = 2.14$) for the P group and $M = 4.33$ ($SD = 2.11$) for the No P group, $t(36) = .31, p = ns;$ and for ratings of interest, $M = 5.08$ ($SD = 1.96$) for the P group and $M = 4.53$ ($SD = 2.43$) for the No P group, $t(36) = .77, p = ns.$ One explanation for the difference in the pattern of emotional ratings between Experiment 3 and Experiments 1 and 2 is that the interactive attribute of a social agency environment is not sufficient to personalize the learning task and help students feel an emotional connection with the agent. The voice and image of the pedagogical agent may be the attributes needed to promote interest in the learning task (Bates, 1994; Lester et al., 1997).

Overall, the results support the constructivist hypothesis for problem-solving transfer by demonstrating an interactivity effect in multimedia learning environments: Students who learn by participating in the learning task with a pedagogical

agent learn more deeply than students who learn in a nonparticipating agent-based environment. Moreover, students who learn by guided discovery remember more of the information used during their interaction. The foregoing results are consistent with past study strategy literature (Elliot et al., 1999), and allow us to conclude that participatory environments encourage the deep processing of the materials of a lesson by engaging students in an active search for meaning (Anderson & Pearson, 1984; Doctorow et al., 1978). However, it should be noted that the PA treatment included both active decision making and contingent feedback, but the non-PA treatment did not. Therefore, it is not possible to discount the effects of contingent feedback.

## EXPERIMENT 4

Experiment 4 set out to identify the relative contribution of image and voice in creating social agency. First, to determine the role of the image of an agent, it compared students' learning in a computer-based environment that included the image of an animated character with an identical lesson in which the agent's image was deleted. Second, to determine the role of the voice of an agent, it compared students' learning in a computer-based environment in which the agent communicated via speech with an identical lesson in which the same words were communicated via on-screen text.

## Method

*Participants and design.*    The participants were 64 college students recruited from the Psychology Subject Pool at the University of California, Santa Barbara. Each participant served in one cell of a $2 \times 2$ between-subject factorial design, with the first factor being modality of the verbal information (narration or text) and the second factor being whether the agent's image was displayed on the computer screen. There were 15 participants in the image and text group (IT Group), 17 participants in the image and narration group (IN Group), 16 participants in the no image and text group (No IT Group), and 16 participants in the no image and narration group (No IN Group). Comparisons were made among the four groups on measures of retention, transfer, and program ratings.

*Materials and apparatus.*    The materials included the same participant questionnaire, retention test, transfer test, and program-rating sheet that were used in Experiment 1.

The computerized materials consisted of four multimedia computer programs on how to design a plant. The IN version was identical to the PA version used in Experi-

ment 1: It included the image of Herman the bug, explanations were narrated, and students designed selected plant parts before listening to the respective explanations. The IT version was identical to the IN version with the exception that the agent's voice was replaced with the same words displayed by on-screen text similar to the No PA version used in Experiment 1. The No IN and No IT versions were identical to the IN and IT versions, except that the agent's image had been deleted throughout the program. All versions were programmed to have the same general duration, which ranged between 24 min and 28 min due to differences in student self-pacing. For the IT and No IT versions, the text was displayed for the same amount of time that the IN and No IN versions played their respective narrations.

*Procedure.*    The procedure was the same as in Experiment 1.

*Scoring.*    A scorer not aware of the treatment condition of each participant determined the retention, transfer, and program-rating scores for each participant in the same fashion as for Experiment 1.

## Results

To determine whether the treatment groups differed on measures of retention, transfer, and program ratings, a two-factor analysis of variance (ANOVA) was conducted for each dependent measure with image (agent present vs. agent not present) and modality (narration vs. text) as the between-subject factor, and retention, transfer, and program ratings as the respective dependent measure.

*Issue 1: Did students who learned with the image of a pedagogical agent learn more deeply than students who learned in the same agency environment without the agent's image?*    One of the hypotheses that Experiment 4 was designed to examine was that the visual presence of the agent would be more likely to promote students' understanding of a multimedia lesson than would a lesson that did not include the agent's visual presence.

Using retention as a dependent measure, the two-factor ANOVA failed to reveal a main effect for image, $F(1, 60) = 2.41$, $MSE = 4.48$, $p = .13$. Groups who were presented with the agent's image ($M = 7.38$, $SD = 1.64$) did not differ in their recall of general information about the plant library from those who were not presented with the agent's image ($M = 7.88$, $SD = 1.21$).

Using transfer as a dependent measure, the two-factor ANOVA failed to reveal a main effect for image, $F(1, 60) = 0.13$, $MSE = 7.74$, $p = .73$. Groups who were presented with the agent's image ($M = 35.00$, $SD = 9.13$) did not differ in their performance from those who were not presented with the agent's image ($M = 35.53$, $SD = 8.51$).

A two-way ANOVA using each program rating as the dependent measure also failed to reveal an image effect for interest, $F(1, 60) = 2.26$; understandability, $F(1, 60) = 0.13$; difficulty, $F(1, 60) = 0.24$; and motivation, $F(1, 60) = 1.40$ (all $ps = ns$). The respective ratings for the image and no image groups were: for interest, $M = 6.02$ ($SD = 2.4$) and 5.14 ($SD = 2.12$); for understandability, $M = 8.00$ ($SD = 1.45$) and $M = 7.88$ ($SD = 1.24$); for difficulty, $M = 5.16$ ($SD = 2.18$) and $M = 4.94$ ($SD = 1.64$); and for motivation, $M = 5.59$ ($SD = 2.69$) and $M = 4.84$ ($SD = 2.16$).

Table 3 shows the mean scores and standard deviations for the IT, No IT, IN, and No IN groups on the retention, transfer, and interest measures. Overall, no evidence was found for an image effect: The visual presence of the agent did not affect students' learning or impressions about the environmental science computer lesson. This finding is not consistent with either the constructivist or the interference hypothesis. On one hand, the absence of an image effect does not support the predictions of the constructivist hypothesis, according to which the use of lifelike characters in a computer lesson should enhance learning by making the lesson more interesting. On the other hand, it does not support the predictions arising from the interference hypothesis, according to which the use of lifelike characters in a computer lesson impairs learning by adding irrelevant visual materials that interfere with the processing of the materials in the lesson.

*Issue 2: Did students who learned with the voice of a pedagogical agent learn more deeply than students who learned in the same agency environment by reading on-screen text?*    The second hypothesis that Experiment 4 was designed to examine was that presenting the verbal material as speech would be more likely to promote students' understanding of a multimedia lesson than presenting the same material as on-screen text.

Using retention as a dependent measure, the two-factor ANOVA revealed a main effect for modality, $F(1, 60) = 9.30$, $MSE = 17.30$, $p < .005$, with a mean number of ideas recalled of 8.12 ($SD = 0.96$) and 7.10 ($SD = 1.70$), respectively, for the narration and text groups. Groups presented with the verbal information in the form of speech recalled significantly more elements from the plant library than those presented with the verbal information in the form of text. There was no significant Image × Modality interaction, $F(1, 60) = 0.06$, $MSE = 0.11$, $p = .81$.

Using transfer as a dependent measure, the two-factor ANOVA revealed a main effect for modality, $F(1, 60) = 16.16$, $MSE = 1000.78$, $p < .0005$, with a mean number of correct answers of 39.09 ($SD = 6.82$) and 31.20 ($SD = 8.85$), respectively, for the narration and text groups. Groups presented with the verbal information in the form of speech gave significantly more correct answers than those presented with the verbal information in the form of text. There was no significant Image × Modality interaction, $F(1, 60) = 1.81$, $MSE = 111.80$, $p = .18$.

TABLE 3
Mean Score on Retention, Transfer, and Interest Tests and Corresponding Standard
Deviations for Four Groups in Experiments 4 and 5

| | Type of Test | | | | | |
| | Retention | | Transfer | | Interest | |
| Group | M | SD | M | SD | M | SD |
|---|---|---|---|---|---|---|
| Experiment 4 | | | | | | |
| IN | 7.82 | 1.13 | 37.47 | 7.32 | 7.00 | 2.33 |
| No IN | 8.45 | 0.63 | 40.81 | 5.98 | 5.75 | 2.00 |
| IT | 6.87 | 2.00 | 32.20 | 10.37 | 4.90 | 2.12 |
| No IT | 7.31 | 1.40 | 30.25 | 7.37 | 4.53 | 2.12 |
| Experiment 5 | | | | | | |
| IN | 8.21 | 0.63 | 40.68 | 6.25 | 5.40 | 2.42 |
| No IN | 8.00 | 0.97 | 39.25 | 6.51 | 5.98 | 2.17 |
| IT | 7.32 | 1.64 | 29.95 | 8.97 | 5.05 | 2.51 |
| No IT | 7.29 | 1.38 | 27.00 | 7.83 | 4.67 | 2.39 |

*Note.* Scores ranged from 0 to 9 for the retention test, from 0 to 60 for the transfer test, and from 5 to 50 for the program-rating scores. IN = image and narration; IT = image and text.

Groups also differed in the interest ratings for the program. A two-way ANOVA using interest ratings as the dependent measure revealed that the narration groups rated their interest in the material significantly greater than the text groups, $F(1, 60) = 9.51$, $MSE = 43.97$, $p < .005$, with a mean rating of 6.39 ($SD = 2.24$) and 4.71 ($SD = 2.09$), respectively, for the narration and text groups. In contrast to differences in ratings based on affect, the groups did not differ on their cognitive assessments of how understandable, $F(1, 60) = 1.04$, $MSE = 1.89$, $p = ns$; how difficult, $F(1, 60) = 0.44$, $MSE = 1.67$, $p = ns$; or how motivating the program was, $F(1, 60) = 0.12$, $MSE = 0.73$, $p = ns$. For ratings of understandability, $M = 8.11$ ($SD = 1.44$) and $M = 7.76$ ($SD = 1.22$); for ratings of difficulty, $M = 4.89$ ($SD = 1.89$) and $M = 5.21$ ($SD = 1.96$); and for ratings of motivation, $M = 5.33$ ($SD = 2.57$) and $M = 5.10$ ($SD = 2.34$), for the narration and text groups, respectively.

Overall, modality effects were obtained on the retention, transfer, and interest, yielding consistent evidence to support the presentation of verbal materials in an auditory modality. The findings of Experiment 4 support the constructivist hypothesis and demonstrate a modality effect in multimedia learning environments: Students remember more of the materials, achieve better transfer, and are more interested in computer-based lessons that communicate the materials via speech rather than via on-screen text.

The benefits of using the voice of a pedagogical agent to communicate with students is consistent with the predictions of the constructivist hypothesis. According to communications research, voices are powerful indicators of social presence and

its incorporation in the interaction might promote richer processing by the incorporation of the additional attitudes and beliefs that are attached to the agent (Reeves & Nass, 1996). However, the results are also consistent with prior findings of modality effects in short-term memory, a superiority in the recall of verbal material when it is presented in an auditory rather than visual modality (Penney, 1989). We interpret the modality effect found in Experiment 4 as a combination of the increased effective working memory from using both visual and auditory channels and the increased interest in learning as indicated by students' higher interest ratings from learning with an agent that offers narrated rather than on-screen text explanations.

## EXPERIMENT 5

The visual presence of the agent in Experiment 4 neither enhanced nor impaired learning. The failure to find an image effect suggests that students' participation and communication modality (auditory rather than visual) are the only factors that account for the deep understanding of an agent-based computer lesson. Alternative explanations are that students ignored the agent's image during the lesson and that the agent's image was not interesting enough to produce a difference in students' motivation to learn. For example, although the fictional agent used in Experiments 1 and 2 had a lively, clear, and expressive voice, he did not have an equivalent image.

First, Herman did not display facial expressions. Visual display of the speaker's mouth can facilitate processing of the auditory message because the lip movements may help disambiguate the sound of words (Hapeshi & Jones, 1992). Additionally, eyebrow, nose, and nonverbal mouth movements (e.g., smiles, grimaces, etc.) convey special meanings to a conversation and provide extra informational sources about a speaker's intent, emotions, or knowledge (Elliott, 1994).

Second, Herman was designed to wear dark sunglasses and therefore never made eye contact with students. Direct gaze is "a salient, arousing, and involving stimulus in social interaction … highly likely to be noticed and to elicit a social interpretation" (Ellsworth, 1975, p. 73). For example, in a study on staring in which participants in a prisoner's dilemma game were paired with a partner who either gazed at them steadily or looked away from them, it was found that individuals in the direct gaze condition had significantly higher heart rates than individuals in the averted gaze condition (Kleinke & Pohlen, 1971). In another study in which participants were asked to look at another person who sometimes met their gaze and sometimes looked away, participants' galvanic skin response increased when their partners looked at them and decreased during the periods of averted gaze (Nichols & Champness, 1971). According to Ellsworth (1975), eye contact has strong attention-getting attributes and therefore it would be expected that a speaker who communicates by making eye contact would receive greater attention from the listener.

Additionally, adults prefer to communicate via a video image that has a higher amount of eye contact with their remote partner (Velthuijsen, Hooijkaas, & Koomen, 1987). They rate their satisfaction with a video teleconferencing system according to the degree of eye contact with their remote partner (Acker & Levitt, 1987). In sum, it seems reasonable to assume that the more rigid the face of a fictional animated agent, the less likely students will take the agent's image as an information element during their communication, and the less involved students will become in a social agency environment.

The goal of Experiment 5 was to test the hypothesis that a more expressive agent, in particular a human agent, could provide additional visual cues to promote deeper learning. The design of Experiment 5 was identical to that of Experiment 4 with the exception that the fictional character Herman the bug was replaced by a video of a real person. The video was a close-up of an expressive drama actor recorded so that the actor would continuously make eye contact with the student during the instructional communication (i.e., the human's eyes in the video were wide open and directed at the student).

## Method

*Participants and design.*    The participants were 79 college students recruited from the Psychology Subject Pool at the University of California, Santa Barbara. Each participant served in one cell of a $2 \times 2$ between-subject factorial design, with the first factor being modality of the verbal information (narration or text), and the second factor being whether or not the agent's image was displayed on the computer screen. There were 19 participants in the image and text group (IT group), 19 participants in the image and narration group (IN group), 21 participants in the no image and text group (No IT Group), and 20 participants in the no image and narration group (No IN Group). Comparisons were made among the four groups on measures of retention, transfer, and program ratings.

*Materials and apparatus.*    The materials included the same participant questionnaire, retention test, transfer test, and program ratings that were used in Experiment 1.

The computerized materials consisted of four multimedia computer programs on how to design a plant. All four versions were identical to the respective versions used for Experiment 4, with two exceptions. First, for the narration versions (IN and No IN), Herman's voice was replaced by the human agent's voice. Second, for the image versions (IN and IT), Herman's animated image was replaced by the video image of the human agent. The voice and image of a male drama student in the Arts Department at the University of California, Santa Barbara was recorded for such purposes. He was an expressive 21-year-old. As in Experiment 4, all ver-

sions were programmed to have the same duration. For the IT and No IT versions, the text was displayed for the same amount of time as the corresponding narrations played in the respective IN and No IN versions. The audio files were created using SoundEdit 16 (Macromedia, 1997), and the video files were created using Premiere 4.2 (Adobe, 1995).

*Procedure.*    The procedure was the same as in Experiment 1.

*Scoring.*    A scorer not aware of the treatment condition of each participant determined the retention, transfer, and program-rating scores for each participant in the same fashion as for Experiment 1.

## Results and Discussion

As in Experiment 1, a two-factor ANOVA was conducted for each dependent measure (retention, transfer, and program rating) with image (present vs. not present) and modality (narration vs. text) as the between-subject factors.

*Issue 1: Did students who learned with the video of a human agent learn more deeply than students who learned in the same agency environment without the agent's video?*    Experiment 5 was designed to examine the hypothesis that a real human agent would create a strong and expressive visual presence, unlike the fictional nonhuman agent used in Experiment 4. More specifically, the hypothesis was that a truly expressive human agent would elicit the same learning mechanisms present in face-to-face communication. Congruently, it was predicted that unlike Experiment 4, a strong image effect would be found for all dependent variables.

Using retention as a dependent measure, the two-factor ANOVA failed to reveal a main effect for image, $F(1, 75) = 0.19$, $MSE = 0.29$, $p = .66$. Groups who were presented with the agent's video did not differ in the mean number of recalled items about the plant library ($M = 7.76$, $SD = 1.30$) from those who were not presented with the agent's video ($M = 7.63$, $SD = 1.24$).

Using transfer as a dependent measure, the two-factor ANOVA failed to reveal a main effect for image, $F(1, 75) = 1.70$, $MSE = 94.63$, $p = .20$. Groups who were presented with the agent's video ($M = 35.32$, $SD = 9.37$) did not differ in the mean transfer test score from those who were not presented with the agent's video ($M = 35.98$, $SD = 9.45$).

Two-way ANOVAs using program ratings as the dependent measures failed to reveal image effects for interest $F(1, 75) = 0.03$, $MSE = 13.43$, $p = ns$; understandability, $F(1, 75) = 2.21$, $MSE = 7.21$, $p = ns$; difficulty, $F(1, 75) = 1.65$, $MSE = 12.24$, $p = ns$; and motivation, $F(1, 75) = 0.02$, $MSE = 2.72$, $p = ns$. The re-

spective ratings for the image and no image groups were as follows: for interest, $M = 5.20$ ($SD = 2.55$) and $M = 5.31$ ($SD = 2.35$); for understandability, $M = 7.68$ ($SD = 1.76$) and $M = 7.11$ ($SD = 1.66$); for difficulty, $M = 4.62$ ($SD = 1.92$) and $M = 5.12$ ($SD = 1.53$); and for motivation, $M = 4.47$ ($SD = 2.42$) and $M = 4.63$ ($SD = 2.33$).

The findings of Experiment 5 replicate those found in Experiment 4, yielding further evidence for the conclusion that a pedagogical agent's image in a multimedia lesson does not hurt, nor does it provide any cognitive or motivational advantage for students' learning. On one hand, the results do not support the constructivist hypothesis, according to which the visual presence of a human pedagogical agent in a multimedia environment promotes deeper understanding as compared to an environment where the agent's image is not present. On the other hand, and similar to Experiment 4, the results do not support the opposite set of predictions arising from the interference hypothesis: The inclusion of the human agent's image in the computer lesson did not detract from processing of the relevant materials.

*Issue 2: Did students who learned with the voice of a human agent learn more deeply than students who learned in the same agency environment by reading on-screen text?*    Using retention as a dependent measure, the two-factor ANOVA revealed a main effect for modality, $F(1, 75) = 8.58$, $MSE = 12.76$, $p < .005$, with a mean number of ideas recalled of 8.10 ($SD = 0.82$) and 7.30 ($SD = 1.49$), respectively, for the narration and text groups. Groups that were presented with the verbal information in the form of speech recalled significantly more elements from the plant library than groups that were presented with the verbal information in the form of text. There was no significant Image × Modality interaction, $F(1, 75) = 0.11$, $MSE = 0.16$, $p = .74$.

Using transfer as a dependent measure, the two-factor ANOVA revealed a main effect for modality, $F(1, 75) = 46.70$, $MSE = 2604.44$, $p = .0001$, with a mean number of correct answers of 39.95 ($SD = 6.35$) and 28.40 ($SD = 8.41$), respectively, for the narration and text groups. Groups that were presented with the verbal information in the form of speech gave significantly more correct answers than those that were presented with the verbal information in the form of text. There was no significant Image × Modality interaction, $F(1, 75) = 0.20$, $MSE = 11.29$, $p = .65$.

A modality effect was confirmed for the perceived difficulty of the program, in which narration groups rated the perceived difficulty significantly lower than text groups, $F(1, 75) = 4.24$, $MSE = 12.24$, $p < .05$, with mean ratings of 4.47 ($SD = 1.41$) and 5.28 ($SD = 1.94$), respectively, for the narration and text groups. Groups did not differ on their cognitive assessments of how interesting, $F(1, 75) = 2.38$, $MSE = 13.43$, $p = ns$; understandable, $F(1, 75) = 2.49$, $MSE = 7.21$, $p = ns$; or motivating the program was, $F(1, 75) = 0.51$, $MSE = 2.72$, $p = ns$. For ratings of interest, $M = 5.69$ ($SD = 2.28$) and $M = 4.85$ ($SD = 2.43$); for ratings of understandability, $M = 7.69$ ($SD = 1.26$) and $M = 7.09$ ($SD = 2.05$); and for ratings of motivation, $M = 4.33$ ($SD = 2.08$) and $M = 4.70$ ($SD = 2.47$), for the narration and text groups, respectively.

The modality effects found in Experiment 5 replicate those of Experiment 4 and are consistent with prior findings of modality effects in short-term memory (Penney, 1989). Additionally, as in short-term memory research, a modality effect has been found in multimedia learning when students who study from visual presentations with narration outperform students who study the same visual presentation with text (Mayer & Moreno, 1998; Moreno & Mayer, 1999; Mousavi, Low, & Sweller, 1995). Moreno and Mayer (1999) proposed that the superiority of simultaneous narrations and animations over simultaneous text and animations is consistent with a dual-processing model of working memory with separate channels for visual and auditory processing. Moreover, the finding that students rated the computer program as being easier when it uses narration rather than on-screen text is consistent with prior findings of the relatively effortless maintenance of the auditory input in comparison to the visual input provided by text (Anderson & Craik, 1974).

## GENERAL DISCUSSION

Despite people's tendency to anthropomorphize by unconsciously ascribing mental states to computers (Laurel, 1997), empirically based principles are needed for the design of social environments in educational technology. As Erickson (1997) noted when he discussed the implications of adapting an agent metaphor, "What is gained by having a character appear on the screen, whether it be a bow-tied human visage, an animated animal character, or just a provocatively named dialog box? … When designers decide to invoke the agent metaphor, what benefits and costs does it bring with it?" (p. 87). He continued, "So far it looks like the agent metaphor is more trouble than it's worth … Far more research is needed on how people experience agents … very simple cues like voice may be sufficient to invoke the agent metaphor" (p. 91).

Based on the finding that interaction with computers can evoke human social responses (Reeves & Nass, 1996), agent developers feel that "the presence of a lifelike character is perhaps the best way to achieve some measure of control over the social and psychological aspects of the interaction" (Ball et al., 1994, p.194). The purpose of the study reported here was to determine the attributes that a social agency environment should possess to promote students' understanding of a computer-based lesson.

### Does Learning With a Pedagogical Agent in a Discovery Environment Promote Constructivist Learning?

Consistent with the pioneering work of Reeves and Nass (1996), Experiments 1 and 2 yield evidence—based on a program-rating questionnaire—that when using media, students like to learn within an agent-based environment more than from other

sources. In addition, Experiments 1 and 2 provide new evidence—from transfer tests—that students learn a computer-based lesson more deeply when it is presented in a social agency environment than when it is presented as a text and graphics source. Thus, this work extends Reeves and Nass's ground-breaking research by focusing on a new dependent measure that taps the depth of learning problem-solving transfer. At the same time, this research extends Dewey's (1913; Renninger et al., 1992) classic theory of academic motivation by offering new empirical support based on learning with media.

By comparing the cognitive consequences of students' experience with or without the aid of a pedagogical agent, our results show that it is possible to create a collaborative learning environment in which students learn more deeply with an animated pedagogical agent, even when the communication is between a single student and a single computer. However, the overarching goal of this set of studies was to pinpoint the specific features of the agency environment that contribute to the meaningful learning of the computer lesson. The constellation of agency features studied included participating with the learner in the process of knowledge construction, having a visual presence, and having an auditory presence.

## Which Features of Agents Affect Student Learning?

At the second stage of our research program, we manipulated the social agency environment to examine which of its three attributes are most important in the promotion of meaningful learning.

First, the results of Experiment 3 show that students who learn in a computer environment that entails participation between agent and learner are more actively involved in the processing of the materials of the lesson than students who learn identical materials in an environment based on a one-way transmission from computer to learner. The findings of Experiment 3 support a teaching-as-communicating view, in which the role of the teacher is to foster the construction of meaningful mental representations in the learner and the role of the learner is to construct mental representations that make sense (Mayer, 1992).

Second, the modality effects found across Experiments 4 and 5 extend existing demonstrations of modality effects in learning from visual and verbal materials (Mayer & Moreno, 1998; Moreno & Mayer, 1999; Mousavi et al., 1995) in three ways: (a) by examining a modality effect in an interactive computer-based multimedia environment rather than a paper-based or noninteractive computer environment, (b) by employing multiple dependent measures including students' rating of the learning materials, and (c) by using fictional and nonfictional pedagogic agents to deliver the verbal materials of the lesson.

Third, the finding that the agent's visual presence did not provide any cognitive or motivational advantage for students' learning across Experiments 4 and 5 suggests that a social agency metaphor might already be present once students interact

with a computer, and trying to make it more visually apparent does not necessarily lead to better results. According to Norman (1990), the perfect interface environment is one in which the interface is transparent to users, with nothing between them and their tasks. The interactivity and modality effects found in our studies seem to support this view, as well as the idea that the affordances of the interface are important.

Overall, the results of this study are consistent with the constructivist hypothesis of multimedia learning according to which a social agency environment is better suited to promote meaningful learning than a more conventional text and graphics environment. No evidence was found to support the interference hypothesis. Despite the fact that social environments provide extra auditory and visual materials—such as the nonverbal information contained in the agent's voice and the verbal and nonverbal information contained in the agent's image, compared to text and graphics environments—it does not hurt students' performance or negatively affect their evaluation of the computer program (Harp & Mayer, 1998; Moreno & Mayer, 2000).

On the practical side, this study has direct implications for instructional design. Despite the wide use of agents in multimedia learning, their introduction is sometimes centered on technological capacity rather than research-based principles (Bradshaw, 1997; Genesereth & Ketchpel, 1994; Laurel, 1990; Maes, 1991). This study offers encouraging evidence for using social agency environments in instructional design. Multimedia programs can result in broader learning if the visual materials are combined with auditory explanations of agents, especially when the student is a participant rather than an observer of the learning environment.

## Limitations and Future Directions

The conclusions we have drawn are limited by the nature of the learning materials and the characteristics of the learners. The learning materials consisted of a discovery-based multimedia environment with short agent interventions explaining how a scientific system works. It is not clear that the same effects would be obtained for nondiscovery environments or environments where an agent's physical interventions provide essential information. For example, if the goal of the instructional material is to teach procedural knowledge, such as how to make a machine work, the use of an agent's image and gestures might play a crucial role by supplementing a conversation with pointing actions and gazes (Hanne & Bullinger, 1992). Similarly, if the subject of the computer lesson was social rather than scientific, learning with the image of an agent might play a fundamental role. Faces in this case could add vital information about the intensity and valence of the social events described (Ellsworth, 1975). More research is needed to investigate the role of agents' visual presence in other multimedia learning situations.

Only low-experience participants were studied. Based on past research, it is likely that high-experience individuals would not have shown the interactivity effects found in Experiment 3, or the modality effects found in Experiments 4 and 5 (Mayer & Moreno, 1998; Moreno & Mayer, 1999). If the interactivity effect resides in promoting more active processing of the materials, and the modality effect depends on increased effective working-memory capacity and less cognitive effort, the low-experience students who lack a mental model for the instructional material would benefit most from interactive, speech-based computer lessons.

Finally, the study did not include any measures of the degree to which students believed that they had formed a social relation with the agent. For example, future studies could include interviews or questionnaires concerning the learner's perception of social communication within agent-based and nonagent-based environments. Future studies could also include online measures of students' facial expressions and eye fixations during learning with and without an agent.

## ACKNOWLEDGMENTS

## REFERENCES

Acker, S. R., & Levitt, S. R. (1987). Designing videoconference facilities for improved eye contact. *Journal of Broadcasting and Electronic Media, 31,* 181–191.

Adobe. (1995). Premiere 4.2 [Computer software]. San Jose, CA: Author.

Anderson, C. M. B., & Craik, F. I. M. (1974). The effect of a concurrent task on recall from primary memory. *Journal of Verbal Learning and Verbal Behavior, 13,* 107–113.

Anderson, J. R. (1983). *The architecture of cognition.* Cambridge, MA: Harvard University Press.

Anderson, R. C., & Pearson, P. D. (1984). A schema-theoretic view of basic processes in reading comprehension. In P. D. Pearson, R. Barr, M. L. Kamil, & P. Mosenthal (Eds.), *Handbook of reading research* (Vol. 1, pp. 255–291). White Plains, NY: Longman.

Anzai, Y., & Simon, H. A. (1979). The theory of learning by doing. *Psychological Review, 86,* 124–140.

Ball, J. E., Ling, D. T., Pugh, D., Skelly, T., Standkosky, A., & Thiel, D. (1994). Demonstration of RE-ACTOR: A system for real-time reactive animations. *CHI'94 conference companion* (pp. 39–40). New York: ACM Press.

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

Bradshaw, J. M. (Ed.). (1997). *Software agents.* Cambridge, MA: MIT Press.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In L. B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 453–494). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Dewey, J. (1913). *Interest and effort in education.* Cambridge, MA: Houghton-Mifflin.

Doctorow, M., Wittrock, M. C., & Marks, C. (1978). Generative processes in reading comprehension. *Journal of Educational Psychology, 70,* 109–118.

Elliot, A. J., McGregor, H. A., & Gable, S. (1999). Achievement goals, study strategies, and exam performance: A mediational analysis. *Journal of Educational Psychology, 91,* 549–563.

Elliott, C. (1994). Research problems in the use of a shallow artificial intelligence model of personality and emotion. *Proceedings of the 12th National Conference on Artificial Intelligence* (pp. 9–15). Seattle, WA: AAAI Press.

Ellsworth, P. C. (1975). Direct gaze as a social stimulus: The example of aggression. In P. Pilner, L. Krames, & T. Alloway (Eds.), *Nonverbal communication of aggression* (pp. 53–75). New York: Plenum.

Erickson, T. (1997). Designing agents as if people mattered. In J. M. Bradshaw (Ed.), *Software agents* (pp. 79–96). Cambridge, MA: MIT Press.

Garner, R., Gillingham, M., & White, C. (1989). Effects of "seductive details" on macroprocessing and microprocessing in adults and children. *Cognition and Instruction, 6,* 41–57.

Genesereth, M. R., & Ketchpel, S. P. (1994). Software agents. *Communications of the ACM, 37*(7), 48–53.

Hanne, K., & Bullinger, H. (1992). Multimodal communication: Integrating text and gestures. In M. M. Blattner & R. B. Dannenberg (Eds.), *Multimedia interface design* (pp. 127–138). New York: ACM Press.

Hapeshi, K., & Jones, D. (1992). Interactive multimedia for instruction: A cognitive analysis of the role of audition and vision. *International Journal of Human–Computer Interaction, 4,* 79–99.

Harp, S. F., & Mayer, R. E. (1998). How seductive details do their damage: A theory of cognitive interest in science learning. *Journal of Educational Psychology, 90,* 414–434.

Kintsch, W. (1980). Learning from text, levels of comprehension, or: Why anyone would read a story anyway? *Poetics, 9,* 87–98.

Kleinke, C. L., & Pohlen, P. D. (1971). Affective and emotional responses as a function of other person's gaze and cooperativeness in a two-person game. *Journal of Personality and Social Psychology, 17,* 308–313.

Laurel, B. (Ed.). (1990). *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. 67–77). Cambridge, MA: MIT Press.

Lester, J., Converse, S. A., Kahler, S. E., Barlow, S. T., Stone, B. A., & Bhogal, R. (1997). The persona effect: Affective impact of animated pedagogical agents. *Proceedings of CHI'97* (pp. 359–366).

Lester, J. C., Stone, B. A., & Stelling, G. D. (1999). Lifelike pedagogical agents for mixed-initiative problem solving in constructivist learning environments. *User Modeling and User-Adapted Interaction, 9,* 1–44.

Macromedia. (1995). Director 4.0.4 [Computer software]. San Francisco: Author.

Macromedia. (1997). SoundEdit 16 [Computer software]. San Francisco: Author.

Maes, P. (Ed.). (1991). *Designing autonomous agents.* Cambridge, MA: MIT Press.

Mayer, R. E. (1992). Cognition and instruction: On their historic meeting within educational psychology. *Journal of Educational Psychology, 84,* 405–412.

Mayer, R. E. (1997). Multimedia learning: Are we asking the right questions? *Educational Psychologist, 32,* 1–19.

Mayer, R. E. (2001). *Multimedia learning.* New York: Cambridge University Press.

Mayer, R. E., Bove, W., Bryman, A., Mars, R., & Tapangco, L. (1996). When less is more: Meaningful learning from visual and verbal summaries of science textbook lessons. *Journal of Educational Psychology, 88,* 64–73.

Mayer, R. E., & Moreno, R. (1998). A split-attention effect in multimedia learning: Evidence for dual processing systems in working memory. *Journal of Educational Psychology, 90,* 312–320.

Mayer, R. E., & Wittrock, M. C. (1996). Problem-solving transfer. In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 47–62). New York: Macmillan.

Moreno, R., & Mayer, R. E. (1999). Cognitive principles of multimedia learning: The role of modality and contiguity effects. *Journal of Educational Psychology, 91,* 358–368.

Moreno, R., & Mayer, R. E. (2000). A coherence effect in multimedia learning: The case for minimizing irrelevant sounds in the design of multimedia instructional messages. *Journal of Educational Psychology, 97,* 117–125.

Mousavi, S., Low, R., & Sweller, J. (1995). Reducing cognitive load by mixing auditory and visual presentation modes. *Journal of Educational Psychology, 87,* 319–334.

National Research Council. (1995). *National science education standards.* Washington, DC: National Academy Press.

Nichols, K. A., & Champness, B. G. (1971). Eye gaze and the GSR. *Journal of Experimental Social Psychology, 7,* 623–626.

Norman, D. A. (1990). *The design of everyday things.* New York: Doubleday.

Penney, C. G. (1989). Modality effects and the structure of short-term verbal memory. *Memory and Cognition, 17,* 398–422.

Reeves, B., & Nass, C. (1996). *The media equation.* New York: Cambridge University Press.

Renninger, K. A., Hidi, S., & Krapp, A. (Eds.). (1992). *The role of interest in learning and development.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Rogoff, B. (1991). Social interaction as apprenticeship in thinking: Guidance and participation in spatial planning. In L. Resnick, J. Levine, & S. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 349–364). Washington, DC: American Psychological Association.

Tharp, R. G., & Gallimore, R. (1988). *Rousing minds to life: Teaching, learning, and schooling in social context.* New York: Cambridge University Press.

Velthuijsen, A., Hooijkaas, C., & Koomen, W. (1987). Image size in interactive television and evaluation of the interaction. *Social Behavior, 2,* 113–118.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Cambridge, MA: Harvard University Press.

Weiner, B. (1990). History of motivational research in education. *Journal of Educational Psychology, 82,* 616–622.

Weinstein, C. E., & Mayer, R. E. (1986). The teaching of learning strategies. In M. Wittrock (Ed.), *Handbook of research on teaching* (pp. 315–327). New York: Macmillan.

Wertsch, J. (1991). *Voices of the mind: A sociocultural approach to mediated action.* Cambridge, MA: Harvard University Press.

Zimmerman, B. J., & Pons, M. M. (1986). Development of a structured interview for assessing student use of self-regulated learning strategies. *American Educational Research Journal, 23,* 614–628.