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Learning Science in Virtual Reality Multimedia Environments: Role of Methods and Media

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College students learned about botany through an agent-based multimedia game. In Experiment 1, students received either spoken or identical on-screen text explanations; in addition, the lesson was presented either via a desktop display (D), a head-mounted display (HMD) used while sitting, or an HMD used while walking (W). In Experiment 2, we examined the effects of presenting explanations as narration (N), text (T), or both (NT) within the D and W conditions. Students scored higher on retention, transfer, and program ratings in N conditions than in T conditions. The NT condition produced results in between. Students gave higher ratings of presence when learning with HMDs, but media did not affect performance on measures of retention, transfer, or program ratings.

Given the potential of virtual reality environments (VREs) for promoting learning (Durlach & Mavor, 1995; Psotka, 1995; Sheridan, 1992), we were interested in how to foster the process of knowledge construction in learners using a VRE. Learning environments can vary in immersion from no immersion (such as illustrated text) to low immersion (such as an educational game presented using a computer display and speakers) to high immersion (such as a computer game presented using a head-mounted display [HMD] and earphones). In comparing no- and low-immersive environments, Moreno, Mayer, Spires, and Lester (2001) found that students learned more deeply when they interacted within an animated agent in a desktop computer game about environmental science—called Design-a-Plant—than when the same material was presented in static form as on-screen text and illustrations (Moreno et al., 2001).

Example of Virtual Reality Environment

Given the advantages of desktop games, a reasonable next step in this program of research is to examine how students learn in more immersive game environments, so we developed a version of Design-A-Plant (Lester, Stone, & Stelling, 1998) that was delivered using an HMD and earphones. In the Design-A-Plant program, students travel to an alien planet that has certain climate conditions (e.g., low rainfall, light sunlight) and must design a plant that would flourish there (e.g., including designing the characteristics of the leaves, stem, and roots). The Design-A-Plant program uses a pedagogic agent who offers individualized advice concerning the relation between plant features and climate conditions by providing students with feedback on the choices that they make in the process of designing plants. For a set of five different planets, the agent first introduces the new weather conditions to the student; second, he asks the student to design the roots that are appropriate for those conditions; third, he gives feedback on students' choice of the root; fourth, he asks the student to design the appropriate stem; fifth, he gives feedback on students' choice of the stem; sixth, he asks the student to design the appropriate leaves; seventh, he gives feedback on students' choice of the leaves; and finally, he takes the student to a new planet. The feedback given for each choice consists of a verbal explanation in the form of narration (N), on-screen text (T), or both (NT). For each of the choices of root, stem, and leaves, students are presented with the corresponding library of plant parts' graphics and names and are asked to click on one of the possible options to design their plant.

In Figure 1, we provide selected frames from the first example problem presented to students who received narrated explanations from the agent; in Figure 2, we provide selected frames from the first example problem presented to students who received the on-screen text explanations from the agent. These frames are only visual examples of the game and do not represent an actual sequence. In the first frame, the agent introduces to the student the new weather conditions for the planet as he says: "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 waiting for the student's choice of the correct root. In the third frame, the agent gives the following explanation after the student has chosen a stem for the planet: "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 had

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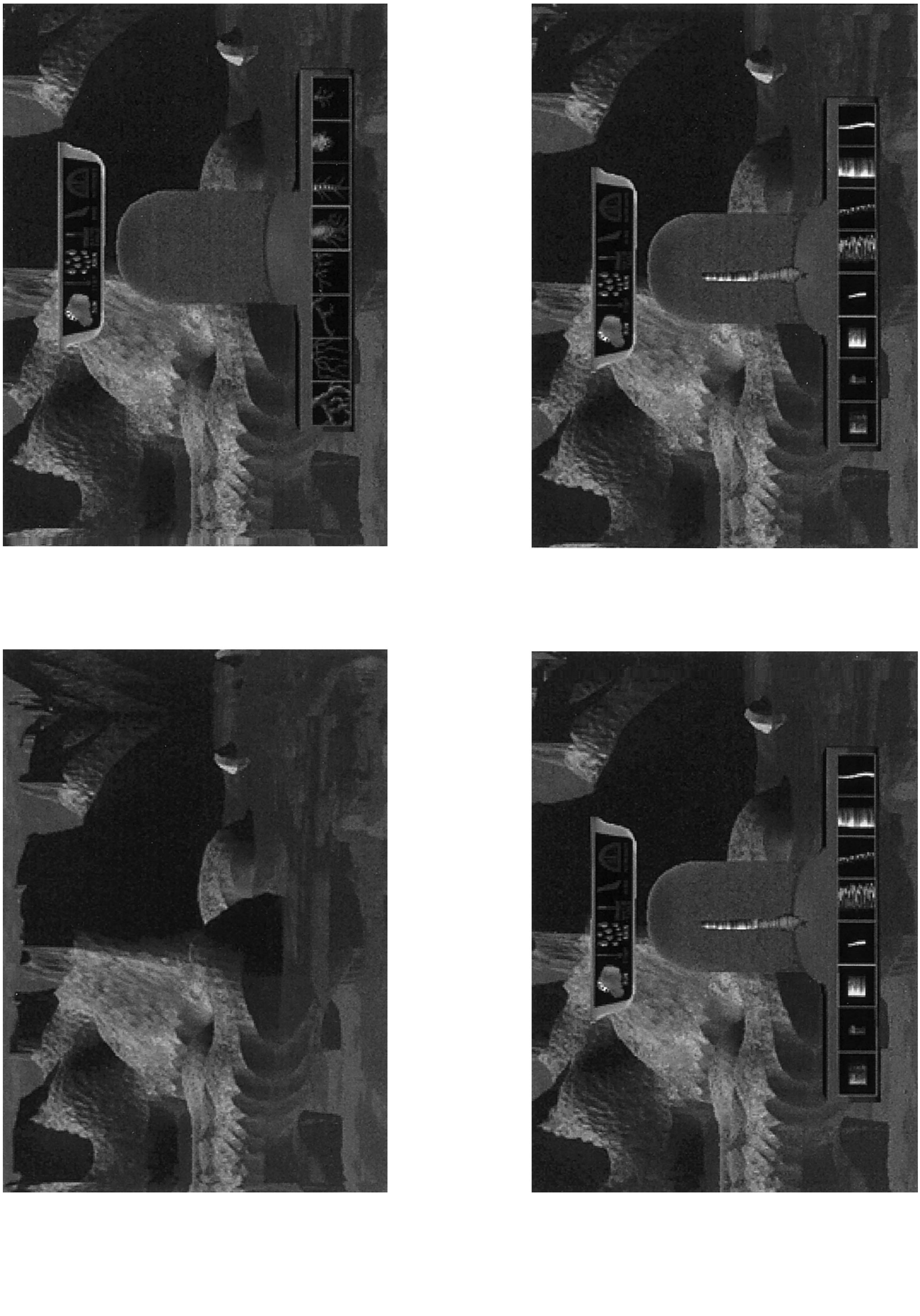


Figure 1. Selected frames from the narration and desktop program.

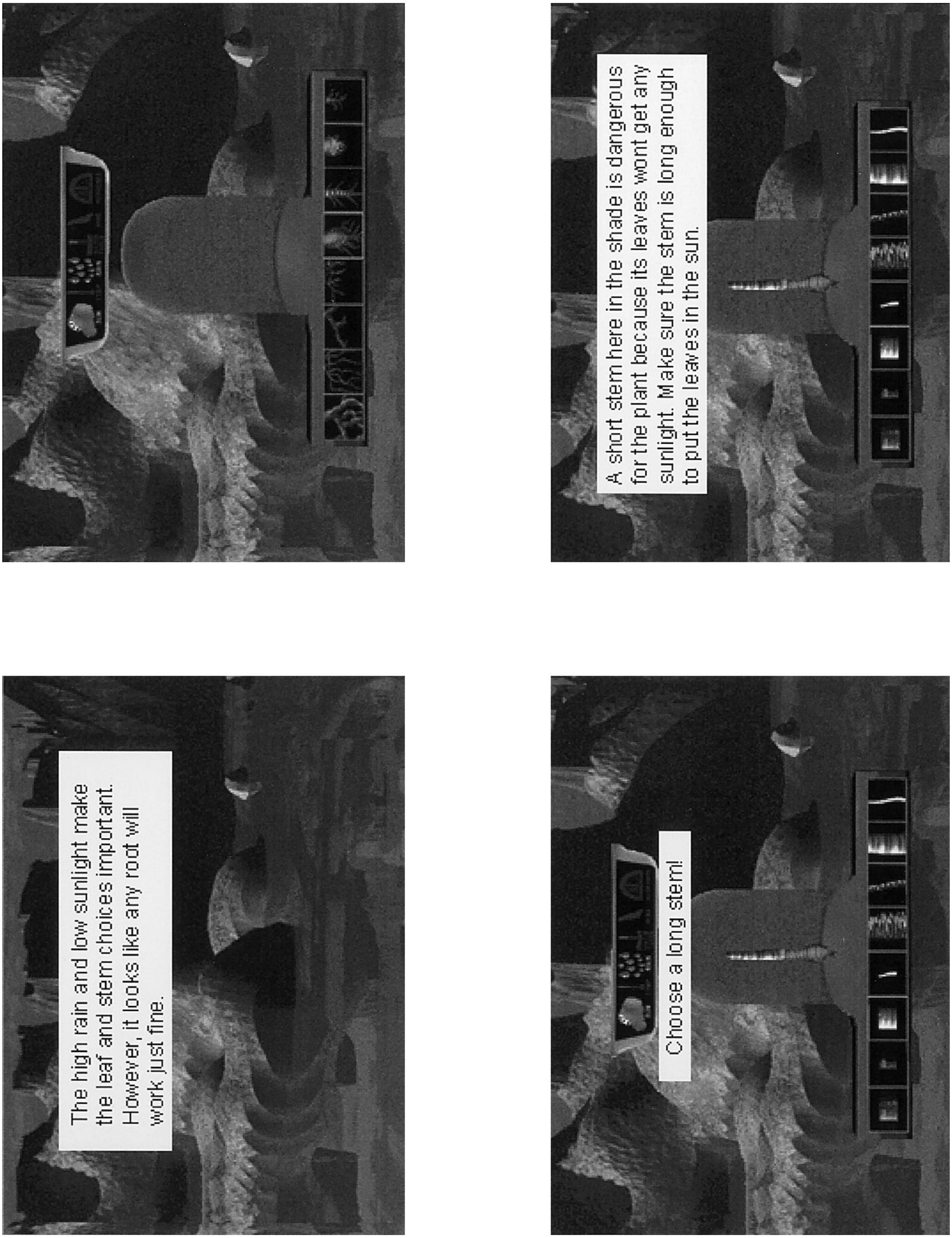


Figure 2. Selected frames from the text and desktop program.

failed in their choice, the agent instructs them to "choose a long stem."

In the present study, we provide an update to the classic distinction between the role of media versus method in promoting learning (Mayer, 2001; Salomon, 1979) by examining two research questions. First, do the same instructional design principles that were discovered with a nonimmersive medium also apply to low-immersion media (e.g., desktop games) and more immersive media (e.g., HMD games)? This is our method question. And second, do students learn more deeply with high-immersion media (e.g., HMD games) as with low-immersion media (e.g., desktop games)? This is our media question.

We focus on three measures of learning: retention—in which we ask students to write down all they can remember about the kinds of roots, stems, and leaves; transfer—in which we ask students to solve problems they have not previously encountered; and program rating—in which we ask students to rate their ease of learning and other features of their learning task. We focus on one measure of presence—in which we ask students to rate their subjective experience of being within the learning environment.

The Role of Method in Virtual Reality Environments

The first goal of this research was to examine the role of method in VREs. Method refers to the instructional method implemented in the design. In Experiment 1, words are presented either in spoken form as narration (N condition) or in printed form as on-screen text (T condition). In nonimmersive multimedia environments (e.g., presentations of animation and narration or animation and on-screen text), we have found that students learned more deeply when words were presented as narration rather than as on-screen text (Mayer & Moreno, 1998; Moreno & Mayer, 1999). This modality effect is consistent with a cognitive theory of multimedia learning, which proposes that the visual information processing channel can become overloaded when it must process incoming graphics and printed text (Mayer, 2001; Moreno & Mayer, 1999; Mousavi, Low, & Sweller, 1995; Sweller, 1999). A goal of Experiments 1 and 2 was to determine whether the modality effect—which was originally discovered in nonimmersive environments—would apply equally well to low-immersion and high-immersion environments, as would be expected on the basis of a cognitive theory of multimedia learning.

In Experiment 2, words are presented as narration (N), text (T), or both simultaneously (NT). In nonimmersive multimedia environments, we have found that students learned more deeply when words were presented as narration rather than as text or as text and narration (Mayer, Heiser, & Lonn, 2001; Moreno & Mayer, 2002). This redundancy effect is consistent with a cognitive theory of multimedia learning, which proposes that the visual information processing channel can become overloaded when it must process incoming graphics and printed text (Mayer, 2001; Moreno & Mayer, 1999; Sweller, 1999). A goal of Experiment 2 was to determine whether the redundancy effect—which was originally discovered in nonimmersive environments—would apply equally well to low-immersion and high-immersion environments, as would be expected on the basis of a cognitive theory of multimedia learning. In summary, our goal was to determine whether instructional method effects hold across different delivery media, that is, whether good design principles in one medium are also good design principles in another medium.

The Role of Media in Virtual Reality Environments

The second goal of this research was to examine the role of media in VREs. Thus, an important research issue concerns whether more immersive media (e.g., learning using HMDs) result in qualitatively different learning outcomes than less immersive media (e.g., learning using desktop computer displays). We define immersion as the extent to which computer displays are capable of delivering an inclusive, extensive, surrounding, and vivid illusion of reality to the senses of a human participant (Slater & Wilbur, 1997). In the present study, we vary the media by comparing how students learn from the same educational game delivered using a desktop display (D), an HMD used while sitting (S), and an HMD used while walking (W). The D condition consisted of students watching the presentation on a computer monitor display, wearing headphones, and navigating the VRE by using the computer mouse. The S condition consisted of students watching the presentation using HMD goggles, wearing a set of integrated headphones, and navigating the VRE with head movements. The W condition was identical to the S condition, but students' navigation was accomplished by head movements and walking inside an empty room.

How can different degrees of immersion in VREs affect learning? First, higher levels of immersion may promote a higher sense of presence, which in turn may promote more engagement and deeper learning. Although immersion is a description of a technology and can be an objective description of what a particular virtual reality (VR) system provides, presence is a subjective state, the psychological sense of being in a VR (Slater & Wilbur, 1997). Presence is an increasing function of immersion in all its aspects. For example, higher levels of immersion in the learning environment induce a higher sense of presence during the learning experience, as measured by participants' ratings (Barfield & Hendrix, 1995; Welch, Blackman, Liu, Mellers, & Stark, 1996). The fundamental idea is that students who learn by participating in the learning task with a higher sense of being in the environment may learn more deeply than students who learn by participating in the learning task as observers (Moreno & Mayer, 2000).

There are several compelling reasons for developing highly immersive environments, including reasons based on interest theory and cognitive load theory. First, according to interest theories of learning (Dewey, 1913), immersive environments create a stronger sense of presence, which in turn motivates and thereby causes the learner to cognitively process the material more deeply. Second, by making the interaction with technology more "natural," immersive learning environments might result in cognitive load reduction (Wetzel, Radtke, & Stern, 1994). Preliminary evidence supports the idea that the richer the perceptual cues and multimodal feedback (e.g., visual, auditory, haptic, etc.), the more likely the transfer of VR training to real-world skill (Jonassen, Peck, & Wilson, 1999; Regian, Shebilske, & Monk, 1992; Schank, 1997). The cognitive advantage of more immersive environments is that they drive students' limited attentional resources to learning the content material rather than to the interface (Hoffman, Prothero, Wells, & Groen, 1998). Ideally, participants who feel a high sense of presence should experience VREs for learning as places visited rather than as images seen and therefore encode their participation as behaviors that would have occurred in everyday reality (Slater & Wilbur, 1997). In summary, our goal was to determine whether high-immersive environments result in better learning than low-immersive environments within each of several different instructional methods.

Methods Versus Media

The decision to use a particular instructional method (N, T, or NT) within a particular delivery medium (D, S, or W) may depend on one's conception of learning. In this section, we consider three different hypotheses and their corresponding predictions: method affects learning, medium affects learning, and medium enables method.

Method Affects Learning

We are particularly interested in the general issue of whether method affects learning across media—that is, whether instructional methods have the same effects within different media environments. If method affects learning, then we expect to find method effects in which performance on tests of retention, transfer, and program rating depend on whether the instructional program presents verbal information as narration, text, or both within each of the VREs we examined. This pattern would be reflected in a main effect for modality in three ways. First, N will be more effective than T for Experiments 1 and 2, and NT will be more effective than T for Experiment 2 because of the expansion of effective working-memory capacity or modality effect (Moreno & Mayer, 1999, 2002). Second, N will be more effective than NT for Experiment 2, because the visual working memories of NT students may become overloaded if they choose to attend to the text. A final prediction based on the method-helps-learning view is that there will be no interaction between method and media. The method-affects-learning hypothesis does not have explicit predictions about presence.

Media Affects Learning

According to this view, highly immersive VREs (such as in the S and W conditions) have the potential of making computer-based learning feel more real by promoting a sense of presence. Therefore, students who learn in more immersive conditions are predicted to give higher presence ratings (i.e., highest ratings for W followed by S and lowest ratings for D). On the basis of interest theory (Renninger, Hidi, & Krapp, 1992), the higher sense of presence could cause students to work harder to learn the material, resulting in high scores on retention, transfer, and program ratings (i.e., highest ratings for W followed by S and lowest ratings for D). This pattern is expected within each instructional method.

An alternative version of this view is that learners will give higher ratings on presence to more immersive learning conditions but that this experiential mode will hurt their learning. On the basis of interference theory, highly immersive environments may overload the learner. The interference view dates back to Dewey's (1913) admonition against viewing interest as extra frills that can be added to an otherwise boring lesson. Any additional material that is not necessary to make the lesson intelligible will reduce effective working-memory capacity and thereby interfere with the learning of the core material (Moreno & Mayer, 2000). As Norman (1993) stated, "rich, dynamic, continually present environments can interfere with reflection: These environments lead one toward the experiential mode, driving the cognition by the perceptions of event-driven processing, thereby not leaving sufficient mental resources for the concentration required for reflection" (p. 23). Thus, students in more immersive environments (e.g., W and S) would score lower than students in less immersive environments (e.g., D) on retention, transfer, and program ratings. This pattern is expected within each instructional method.

Media Enables Method

A third view is that method affects learning, but that certain media enable certain methods. For example, an interactive game involves a different instructional method than presenting static text and illustrations; however, a textbook medium allows only the second method, whereas a computer medium allows both methods. We investigated only a mild form of this view in the present studies, namely that more immersive environments enable a richer experience with well-designed games (e.g., N condition) than poorly designed games (e.g., T or NT) so modality and redundancy effects should be stronger within high-immersion (W) media than within low immersion (D) media. This interaction between method and media is expected for all three measures of learning—retention, transfer, and program rating. As summarized in Table 1, the three hypotheses offer different predictions on presence, retention, transfer, and program ratings. A goal of the present study was to examine the apparent conflict among these views.

Experiment 1

Method

Participants and design. The participants were 89 college students from the psychology participant pool at the University of California, Santa Barbara. Each participant served in one cell of a 2 $\times$ 3 between-subjects factorial design, with the first factor being modality of the verbal information (N or T) and the second factor being the level of immersion during the computer interaction (D, S, or W). There were 17 participants in the ND group, 17 participants in the TD group, 13 participants in the NS group, 13 participants in the TS group, 13 participants in the NW group, and 14 participants in the TW group. Because some instructional effects are stronger for low-experience learners than for high-experience learners (Mayer, 2001), only low-experience students were included in our study. There were no significant differences on gender, age, GPA scores, or SAT scores between groups. Comparisons were made among the six groups on measures of retention, transfer, presence, and program ratings.

Materials and apparatus. For each participant, the paper-and-pencil materials consisted of a participant questionnaire (which was used as a pretest), a presence questionnaire, a retention test, a seven-page problem-solving test, and a program-rating sheet (which were used as dependent measures). All were typed on 8.5 $\times$ 11-in. sheets of paper. The participant questionnaire solicited information concerning the participant's name, GPA scores, SAT scores, and gender. In addition, to measure the participant's knowledge of botany, it contained the following two questions: (a) "Please put a check mark indicating your knowledge of botany" followed by five blanks ranging from 1 (*very little*) to 5 (*very much*), and (b) "Please place a check mark next to the items that apply to you: ___ I have taken a class in botany. ___ I have houseplants. ___ I have eaten a plant or

Table 1
Three Views Concerning Method and Media

View	General prediction	Specific prediction in Experiments 1 and 2
Method affects learning	Method helps learning: Learning depends on instructional method within every delivery medium.	Method effect: Better retention, transfer, and rating scores for animation with narration than for animation with on-screen text (in high- and low-immersion environments).
Media affects learning	Media helps learning: Learning depends on delivery medium for every instructional method.	Media effect: Better retention, transfer, and rating scores for high-immersion environment than for low-immersion environment (for each instruction method).
	Media hurts learning: Learning depends on delivery medium for every instructional method.	Media effect: Poorer retention, transfer, and rating scores for high-immersion environment than for low-immersion environment (for each instructional method).
Media enables method	Method helps learning for certain media: Learning depends on instructional method; instructional method is made possible by delivery medium.	Method × Media interaction: Better retention, transfer, and rating performance for animation with narration than animation with on-screen text in high-immersion environment but not in low-immersion environment.

vegetable that I grew myself. ___ I have made my own mulch. ___ I know what a pistil is. ___ I know why plant leaves are green.

The presence questionnaire was based on Witmer and Singer's (1998) self-assessment instrument for measuring students' sense of presence in a virtual environment. It contained 13 statements along with the following instructions: "Indicate the extent to which you agree with each of the following statements. Please read the questions very carefully and write the number corresponding to your answer on the line next to each question (with –3 *as strongly disagree*, –2 as *disagree*, –1 as *somewhat disagree*, 0 as *neither agree or disagree*, 1 as *somewhat agree*, 2 as *agree*, and 3 as *strongly agree*)." The 13 statements were the following: (1) "I felt that I was able to control events in the environment." (2) "The environment was responsive to actions that I performed." (3) "My interaction with the environment seemed very natural." (4) "The visual aspect of the virtual environment was compelling." (5) "It was easy for me to look around in the environment." (6) "I felt like the objects in the environment were really present and moving around me." (7) "My experience in the environment was consistent with my experiences in the real world." (8) "I was completely able to actively survey or search the environment using vision." (9) "I felt very proficient at interacting with the environment by the end of the session." (10) "I felt like I was really in the environment." (11) "While I was in the environment, I experienced a strong sense of *Presence*. (*Presence* is defined as the subjective experience of being in one place or environment, even when one is physically situated in another.)" (12) "The computer environment was very involving." (13) "I felt like I was immersed (or included in) and interacting with the computer environment." The internal consistency coefficient (Cronbach's alpha) for the presence questionnaire was .86.

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. The first five problem-solving sheets, respectively, had the following statement at the top: (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 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." In each of 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. Figure 3 shows the sheet for the first problem.

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 while 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; branching, shallow, and thin roots. Problem 7 consisted of a plant with thick, small, thick-skinned leaves; thick, long, and bark stem; nonbranching, deep, and thick roots. Finally, at the bottom of each sheet the following question appeared for each problem: "Why do you think that the plant designed will flourish in the environment that you chose?"

The program-rating sheet contained eight questions asking participants to rate on a 10-point scale their level of motivation and interest, and the helpfulness, friendliness, and perceived difficulty of the material. The following two questions were intended to assess the learner's interest level: "How interesting is this material?" (scale ranged from 1 [*boring*] to 10 [*interesting*]) and "How entertaining is this material?" (scale ranged from 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?" (scale ranged from 1 [*not eager*] to 10 [*very eager*]). The following two questions were intended to assess how much the program helped students' understanding: "How much does this material help you understand the relation between plant design and the environment?" (scale ranged from 1 [*not at all*] to 10 [*very much*]) and "How helpful is this material for learning about plant design?" (scale ranged from 1 [*unhelpful*] to 10 [*helpful*]). The following question was intended to assess the learner's rating of the program's friendliness: "How friendly was the computer that you interacted with?," and participants had to rate on a 10-point scale the level of friendliness (scale ranged from 1 [*not very friendly*] to 10 [*very friendly*]). The following two questions were intended to assess the learner's perception of learning difficulty: "How difficult was the material?" (scale ranged from 1 [*easy*] to 10 [*difficult*]) and "How much effort is required to learn the material?" (scale ranged from 1 [*little*] to 10 [*much*]). The internal consistency coefficient (Cronbach's alpha) for the program ratings questionnaire was .78.

The computerized materials consisted of six multimedia computer programs on how to design a plant (which constituted manipulations of the independent variables). All versions contained the same graphics representing the environments and plant structures and the same verbal material. The TD, TS, and TW versions of the program included the same expla-

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

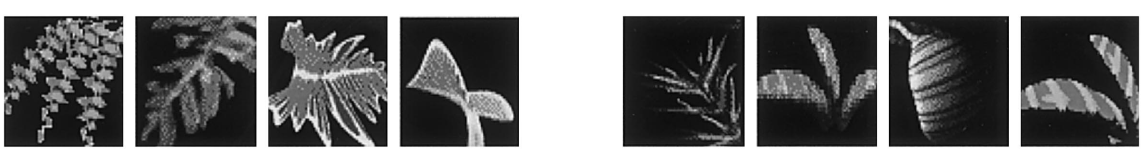
Circle the types of stem (1 or more):

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, Thick skin	Small, Thin skin	Large, Thin skin	Large, Thick skin	Small, Thick skin	Small, Thin skin	Large, Thin skin	Large, 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.

nations presented in the ND, NS, and NW versions but instead of being in the form of narration they were provided as text. The text was displayed for the same amount of time that the respective narrations lasted while playing. The desktop versions of the program (TD and ND) were designed so that students could view the virtual environment by looking at the computer screen and move around the environment by using the computer mouse. The sitting HMD versions of the program (NS and TS) were designed so that students would use the HMD to view and explore the virtual environment by moving their head while sitting at a computer station. The walking HMD versions of the program (NW and TW) were identical to the respective HMD sitting versions (NS and TS), except that students could walk around the virtual environment for exploration. For all versions, students could highlight the options in the root, stem, and leaf menus by turning the joystick knob and could select plant parts by clicking on the right button of the joystick. All versions required between 10 and 16 min to complete, depending on the pace of the learner. All students visited five planets, with the following environmental conditions: low sun and high rain; low rain; low rain and high temperature; low rain, low sun, high temperature, and low nutrients; and low rain, low temperature, and high water table. The six multimedia programs were developed using SoundEdit 16 (Macromedia, 1997), Photoshop 4.2 (Adobe, 1995), and 3D Studio Max (Kinetix, 1999). Examples of frames from the narrated and text versions of the program are presented in Figures 1 and 2, respectively.

The VR system was comprised of a Virtual Research (Aptos, CA) VH HMD, an optical tracking system, and a handheld joystick. The HMD was stereo capable with a pixel resolution of 640 horizontal $\times$ 480 vertical at a 72 Hz refresh rate. The optics of the device project a virtual image at approximately 8 feet that subtends 50 ° horizontal $\times$ 38 ° vertical of visual angle. The optical tracking system was a commercially available product by Intersense (Burlington, MA), which can measure orientation with a resolution of 1 part in 18,000 (e.g., 0.02 ° along each axis of rotation) and has a latency of less than 5 ms. The hand-held joystick contained one button to make selections and a rotating knob to highlight the root, stem, and leave menus. The computer systems included two Gateway computers, each with a 400 MHz processor and a 14-in. monitor. Sony headphones were used in D conditions.

Procedure. Participants were tested in groups of 1 or 2 per session. Each participant was randomly assigned to a treatment group and was either seated at an individual cubicle in front of a computer (ND, TD, NS, and TS conditions) or placed in the middle of the testing room (NW and TW conditions). First, participants completed the participant questionnaire at their own rate. Second, 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. Third, participants were instructed about the use of the specialized equipment. All students used a special joystick to interact with the computer program consisting of one button to make selections and a knob to highlight the different options in the root, stem, and leaf menus. Additionally, participants were instructed about how to explore the virtual environments in their respective condition: by using the mouse (ND and TD), moving their head (NS and TS), or walking and moving their head (NW and TW). Fourth, students in the ND group were told to put on headphones, and all participants in HMD conditions were assisted with the set up and adjustment of the VR equipment. Then, students were given a few minutes in each condition to practice the respective navigation method until the experimenter considered that students were familiar enough to interact with the program. The experimenter explained first, for the D condition, how rolling the mouse in different directions allowed the student to navigate within the VRE. Second, for the HMD and sitting condition (S), the experimenter explained how moving the head from a seated position allowed the student to navigate within the VRE. Third, for the HMD and walking condition (H), the experimenter explained how moving the head from a standing position and walking allowed the student to navigate within the VRE. Finally, students were instructed to navigate in the environment without assistance until the experimenter considered that the navigation skills had been mastered. Once students demonstrated good navigation skills, the experimenter asked students if they had any questions or if they were ready to start, and if no further questions were asked, the experimenter pressed the *S* key to start each participant in the program.

Then, all participants were instructed to press the joystick button to begin the program. On pressing the button, the respective version of the multimedia program was presented once to all participants. All participants visited five different environments. Fifth, when the program was finished, the experimenter assisted students in NH, TH, NW, and TW conditions remove the HMD equipment, and all participants were presented with oral instructions for the test, stating that there would be a series of question sheets and that for each the participant should keep working until told to stop. Sixth, the presence questionnaire was presented and collected after 3 min. Seventh, the program-rating sheet was presented and collected after 3 min. Then, the retention sheet was distributed. After 5 min, the sheet was collected. Finally, 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. The methodology for Experiment 1 is summarized in the top of Table 2.

Scoring. A scorer not aware of the treatment condition of each participant determined the presence, retention, transfer, and program-rating scores for each participant. A presence score was computed for each participant by adding the numbers that the participant had circled in the presence sheet. A retention score was computed for each participant by counting the number of correct categories (out of nine possible) for each plant part (root, stem, and leaf) that the participant produced on the retention test. The transfer score was computed for each participant by counting the number of acceptable answers (out of 60 possible) that the

Table 2
Methodology for Experiment 1

	Method	
Medium	Animation and narration	Animation and printed text
Desktop	Narration–desktop: Receive animation and narration on a computer screen; respond by mouse click.	Text–desktop: Receive animation and printed text on a computer screen; respond by mouse click.
Sitting HMD	Narration–sitting HMD: Receive animation and narration using HMD; navigate by joystick and head movement; respond by button press.	Text–sitting HMD: Receive animation and printed text using HMD; navigate by joystick and head movement; respond by button press.
Walking HMD	Narration–walking HMD: Receive animation and narration using HMD; navigate by walking and head movement; respond by button press.	Text–walking HMD: Receive animation and printed text using HMD; navigate by walking and head movement; respond by button press.

Note. HMD = head-mounted display.

participant produced across the seven transfer problems. For each of the first five questions, 1 point was given for each correct category that the participant circled for each plant part and 1 point was given for each correctly stated explanation about the participant's choice of category of plant type, regardless of wording. For example, for transfer question Number 2, 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, 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 explanation 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 4) and 1 point was given for each correctly stated explanation about their choice of type of environment, regardless of wording. Also, program ratings were computed by adding the numbers that participants had circled in the program-rating sheet.

The botany knowledge scale was scored by assigning 1 point for each item checked on the six-item list and assigning an additional 1 to 5 points corresponding to the participant's self-rating of botany knowledge (scale ranged from 1 [*very little*] to 5 [*very much*]). We eliminated the data for any student who scored above 6 and replaced it with the data of a new student. Using this procedure, 6 students were replaced in Experiment 1.

Results

Table 3 shows the means and standard deviations for each of the six treatment groups on each of four dependent measures: presence, retention, transfer, and program ratings. For each measure, we conducted a two-way analysis of variance (ANOVA), with the first factor being the medium (D, S, or W) and the second factor being method (N or T).

Issue 1: Do students experience a stronger sense of presence in more immersive VREs? Consistent with past research in VREs, we predicted that higher levels of immersion in the learning environment would induce a higher sense of presence during the learning experience (Barfield & Hendrix, 1995; Welch et al., 1996). Using presence as a dependent measure, there was main effect for medium, $F(2, 84) = 8.08$, $MSE = 1{,}117.47$, $p < .01$. On the basis of supplemental Tukey tests (with $\alpha = .05$), students in D groups rated their sense of presence significantly lower than students in H and W groups, which did not differ from each other (Ms = –2.59, 7.31, and 8.22; SDs = 12.49, 10.03, and 12.33, for D, S, and W groups, respectively). Media has an effect on students' sense of presence, with students reporting a stronger feeling of "being there" with programs delivered using HMDs rather than desktop displays.

Issue 2: Do more immersive VREs promote deeper (or less) learning than less immersive VREs? One version of the media-affects-learning view holds that more immersive VREs are more likely to promote students' learning of the science lesson, by virtue of inducing higher levels of presence. Another version of the media-affects-learning view holds that more immersive VREs are more likely to distract learners and result in lower levels of learning. Using retention as a dependent measure, there was no main effect for medium, $F(2, 81) = 0.90$, $MSE = 2.85$, $p = .41$. Groups presented with higher levels of immersion did not differ in the mean number of recalled items about the plant library from those presented with lower levels of immersion (Ms = 6.01, 6.50, and 5.82; SDs = 1.85, 1.85, and 2.04, for D, S, and W groups, respectively). There was no significant interaction between medium and method, $F(2, 81) = 0.73$, $MSE = 2.32$, $p = .49$.

Using transfer as a dependent measure, we found no main effect for medium, $F(2, 81) = 0.01$, $MSE = 1.01$, $p = .99$. Groups presented with higher levels of immersion did not differ in the mean number of answers from those presented with lower levels of immersion (Ms = 31.06, 30.69, and 30.52; SDs = 9.54, 9.20, and 11.68, for the D, S, and W groups, respectively). A significant interaction was found between medium and method, $F(2, 81) = 4.56$, $MSE = 316.27$, $p < .05$. To determine the nature of this interaction, we conducted post hoc analysis of simple effects for modality and immersion. For both the D and S conditions, receiving information using on-screen text rather than using narration proved to significantly hinder students' learning, as measured by transfer scores, $F(1, 81) = 8.08$ and 33.05, MSE = 560.12 and 33.05, ps $< .01$, respectively. There were no significant simple effects in which students performed better in a more

Table 3
Mean Scores on Presence, Retention, Transfer, and Program Ratings and Corresponding Standard Deviations for Six Groups—Experiment 1

	Type of test							
	Presence		Retention		Transfer		Program rating	
Group (method–medium)	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Narration–desktop	1.59	10.71	6.53	1.77	35.12	8.74	31.65	5.57
Text–desktop	6.77	13.05	5.65	1.87	27.00	8.74	25.71	6.34
Narration–sitting HMD	8.69	9.38	7.23	1.69	3.46	9.82	33.15	5.27
Text–sitting HMD	5.92	10.85	5.77	1.74	27.92	7.95	30.50	8.43
Narration–walking HMD	8.31	10.80	6.85	0.80	40.08	4.37	32.39	7.02
Text–walking HMD	8.14	14.01	4.86	2.38	21.64	8.88	30.71	6.90
Summary								
Effect for medium	Yes		No		No		No	
Effect for method	No		Yes		Yes		Yes	
Interaction	No		No		No		No	

Note. The potential range was −39 to 39 for the presence scores, 0 to 9 for the retention test, 0 to 60 for the transfer test, and 8 to 80 for the program-rating scores. HMD = head-mounted display.

immersive environment (e.g., S or W) than in a less immersive environment (e.g., D).

Using the overall program rating as the dependent measure, we found no significant main effect for medium, $F(2, 81) = 2.16$, $MSE = 94.26$, $p = .12$. The respective ratings for the D, H, and W groups, respectively, were as follows: *Ms* = 28.67, 31.83, and 31.52; *SD*s = 6.61, 7.02, and 6.88. There was no significant interaction between medium and method, $F(2, 81) = 0.89$, $MSE = 38.74$, $p = .42$.

Did media affect learning? Students who learned in more immersive VREs felt a higher level of presence. However, groups did not differ in their learning outcomes. The increased sense of presence did not lead to increased or decreased learning. These results are not consistent with the view that highly immersive media promote interest and effort in learning, or that highly immersive media impede learning.

Issue 3: Do students who learn with narration learn more deeply than students who learn in the same VRE by reading on-screen text? The method-affects-learning view holds that presenting verbal material as speech is more likely to promote students' understanding of a multimedia lesson than presenting the same material as on-screen text, regardless of delivery medium. Using retention as a dependent measure, there was a significant main effect for method, $F(1, 81) = 14.03$, $MSE = 44.72$, $p < .01$, with the N groups recalling significantly more ideas ($M = 6.84$, $SD = 1.51$) than the T groups ($M = 5.43$, $SD = 2.01$). 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.

Using transfer as a dependent measure, we found a significant main effect for method, $F(1, 81) = 35.39$, $MSE = 2{,}452.76$, $p < .01$, with the N groups generating significantly more correct answers ($M = 36.12$, $SD = 8.34$) than the T groups ($M = 25.57$, $SD = 8.80$). 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.

Using program ratings as the dependent measure, we found a significant main effect for method, $F(1, 81) = 5.75$, $MSE = 250.99$, $p < .05$, in which the N groups rated the program more favorably ($M = 32.33$, $SD = 5.85$) than the T groups ($M = 28.72$, $SD = 7.42$).

Did method affect learning? Method effects were obtained on the retention, transfer, and overall program ratings yielding consistent evidence to support the method-affects-learning hypothesis. More specifically, there was a modality effect in VREs: Students remember more of the materials, achieve better transfer, and rate more favorably VREs that communicate the materials using speech rather than using on-screen text. There was no consistent evidence for the media-enables-method view, because the modality effect was obtained for high- and low-immersion environments. These conclusions are summarized in the bottom three rows of Table 3.

Experiment 2

In Experiment 1, we found preliminary evidence for the method-affects-learning hypothesis by demonstrating a modality effect for measures of retention, transfer, and program ratings. On the other hand, we found no evidence in favor of the media-affects-learning hypothesis. The purpose of Experiment 2 was to test these hypotheses using a different type of instructional method. In Experiment 2, we focused on the least and most immersive media conditions used in Experiment 1—presenting material using a desktop display (D) or using an HMD that allowed for the participant to walk (W). In Experiment 2, we examined three methods—presenting words as narration (N), as printed text (T), or as both (NT). Thus, in addition to the two methods used in Experiment 1 (N and T), we added a redundancy condition (NT) in which students received simultaneous narration and printed text. In all treatments, students saw the same animations.

Method

Participants and design. The participants were 75 college students recruited from the psychology participant pool at the University of California, Santa Barbara. Each participant served in one cell of a 3 × 2 between-subjects factorial design, with the first factor being modality of the verbal information (N, T, or NT) and the second factor being the level of immersion during the computer interaction (D or W). There were 14 participants in the ND group, 14 participants in the TD group, 14 participants in the NTD group, 11 participants in the TW group, 10 participants in the NW group, and 12 participants in the NTW group. Comparisons were made among the six groups on measures of retention, transfer, presence, and program ratings. There were no significant differences on gender, age, or GPA and SAT scores between groups. Using the same procedure as in Experiment 1, 8 students who indicated that they possessed high knowledge in botany were replaced.

Materials and apparatus. For each participant, the paper-and-pencil materials and apparatus were identical to those used in Experiment 1 for D and H conditions, respectively.

The computerized materials consisted of six computer programs on how to design a plant. The ND, NW, TD, and TW versions were identical to the respective versions used in Experiment 1. The NTD and NTW versions were identical to the respective ND and NW versions, with the exception that identical words were presented as on-screen text concurrent to the spoken explanations.

Procedure. The procedure was identical to that used in Experiment 1.

Scoring. The presence, retention, transfer, and program ratings scores for each participant were computed identically to the way they were computed in Experiment 1.

Results

The means and standard deviations for each of the six treatment groups on each of four dependent measures (presence, retention, transfer, and program ratings) are in Table 4. For each measure we conducted a two-way ANOVA, with the first factor being the medium (D or W) and the second factor being method (N, T, or NT).

Issue 1: Do students experience a stronger sense of presence in more immersive VREs? On the basis of the medium-affects-learning hypothesis, we predicted that learning in the W condition would induce a stronger sense of presence in students than learning in the D condition as measured by the presence questionnaire. Using presence as a dependent measure, there was a main effect for medium, $F(1, 73) = 4.93$, $MSE = 1{,}158.53$, $p = .03$, in which students in the W groups ($M = 8.73$, $SD = 17.93$) rated their sense of presence significantly higher than students in the D groups ($M = 1.81$, $SD = 12.95$). As in Experiment 1, programs delivered

Table 4
Mean Scores on Presence, Retention, Transfer, and Program Ratings and Corresponding Standard Deviations for Six Groups—Experiment 2

Group (method—medium)	Presence *M*	Presence *SD*	Retention *M*	Retention *SD*	Transfer *M*	Transfer *SD*	Program ratings *M*	Program ratings *SD*
Narration–desktop	4.71	15.54	7.57	1.09	30.29	6.01	33.21	5.19
Text–desktop	−3.43	12.64	6.07	1.77	25.29	7.46	27.64	8.43
Both–desktop	1.14	9.57	6.79	1.42	28.93	8.36	29.57	6.09
Narration–walking HMD	17.88	12.53	6.80	2.04	34.60	5.72	31.60	5.72
Text–walking HMD	−3.22	17.85	5.64	1.12	24.27	3.52	25.09	6.01
Both–walking HMD	9.83	17.83	7.17	1.53	32.92	7.68	29.00	7.95
Summary								
Effect for medium	Yes		No		No		No	
Effect for method	No		Yes		Yes		Yes	
Interaction	No		No		Yes		No	

Note. The potential score was −39 to 39 for the presence scores, 0 to 9 for the retention test, 0 to 60 for the transfer test, and 8 to 80 for the program-rating scores. HMD = head-mounted display.

using HMDs rather than desktop displays induced higher levels of presence in students.

Issue 2: Do more immersive VREs promote deeper (or less) learning than less immersive VREs? Using retention as a dependent measure, there was no significant main effect for immersion, $F(1, 69) = 0.61$, $MSE = 1.40$, $p = .44$. Groups who learned in the D conditions did not differ in the mean number of recalled items about the plant library from groups who learned with higher levels of immersion (*M*s = 6.81 and 6.55; *SD*s = 1.55 and 1.68, for D and W groups, respectively). There was no significant interaction between medium and method, $F(1, 69) = 0.95$, $MSE = 2.18$, $p = .39$.

Using transfer as a dependent measure, we found no significant main effect for medium, $F(1, 69) = 2.37$, $MSE = 108.77$, $p = .13$. Groups presented with a higher level of immersion did not differ in the mean number of answers from groups presented with a lower level of immersion (*M*s = 28.17 and 30.55; *SD*s = 7.47 and 7.36, for the D and W groups, respectively). There was no significant interaction between medium and method, $F(1, 69) = 1.19$, $MSE = 54.71$, $p = .31$.

Using the overall program rating as the dependent measure, we found no significant main effect for medium, $F(1, 69) = 1.02$, $MSE = 45.95$, $p = .32$. The respective ratings for the D and W groups were as follows: *M*s = 30.14 and 28.49, *SD*s = 6.95 and 7.02. There was no significant interaction between medium and method, $F(2, 69) = 0.14$, $MSE = 6.20$, $p = .87$.

Did media affect learning? No media effects were found on any of the dependent measures, and no interaction was found between medium and method. Similar to Experiment 1, despite the higher presence ratings given to more immersive VR conditions, students' learning was not affected by media. In conclusion, the findings fail to support a media-helps-learning or media-hurts-learning hypothesis.

Issue 3: Do students who learn with narration or with narration and text learn more deeply than students who learn in the same VRE by reading text? Using retention as a dependent measure, there was a main effect for method, $F(2, 69) = 5.45$, $MSE = 12.52$, $p < .01$, with a mean number of ideas recalled of 7.25, 5.88, and 6.96, respectively, for the N, T, and NT groups (*SD*s = 1.57, 1.51, and 1.46, respectively). We conducted supplemental Tukey tests (with $\alpha = .05$) and found that T groups recalled significantly fewer items than N and NT groups, which did not differ from each other.

Using transfer as a dependent measure, we found a significant main effect for method, $F(2, 69) = 8.73$, $MSE = 400.95$, $p < .01$, with a mean number of correct answers of 32.08, 24.84, and 30.77, respectively, for the N, T, and NT groups (*SD*s = 6.16, 5.96, and 8.15, respectively). We conducted supplemental Tukey tests (with $\alpha = .05$) and found that T groups gave significantly fewer correct answers on problem-solving transfer tests than N and NT groups, which did not differ from each other.

Using program ratings as the dependent measure revealed a main effect for method, $F(2, 69) = 4.86$, $MSE = 218.63$, $p = .01$, with a mean rating of 32.54, 26.52, and 29.31, respectively, for the N, T, and NT groups (*SD*s = 5.36, 7.43, and 6.87, respectively). We conducted supplemental Tukey tests (with $\alpha = .05$) and found that T groups gave significantly lower program ratings than students in N groups.

Did method affect learning? Overall, method effects were obtained on the retention, transfer, and overall program ratings replicating the pattern found in Experiment 1 and thus supporting the method-affects-learning hypothesis. Consistent with this hypothesis, learning with animation and narration or with animation and narration plus on-screen text is more efficient than learning with animation and on-screen text. Although the N groups outperformed the T groups on retention, transfer, and program ratings scores, the N and NT groups did not differ from each other. That is, for both desktop and HMD environments, adding redundant on-screen text to spoken explanations did not hurt or help students' learning. The findings seem to contradict prior studies on verbal redundancy in multimedia learning (Mayer et al., 2001; Moreno & Mayer, 2002). A possible interpretation for NT groups performing comparably with N groups is that students in NT groups may have been inclined to attend to the narration alone because of the experiential mode of VREs. When students are exploring an environment (either by moving the computer mouse or by moving their head), it is less likely that they will read a box containing text if they can obtain the same information by listening to a narration. There was no support for the medium-enables-method view in this study, because the modality and redundancy effects were consistent across two different media. These conclusions are summarized in the bottom three rows of Table 4.

General Discussion

Research on learning in virtual environments represents an important extension of the current research base in instructional technology (Jacobson & Kozma, 2000; Lajoie, 2000). For VREs to be effective instructional tools, it is not sufficient to focus solely on maximizing the fidelity of object renderings and behaviors (Johnson, Rickel, Stiles, & Munro, 1998); one must consider how the environment can facilitate effective learning experiences by focusing on a cognitive theory of how people learn from technology (Mayer, 2001; Moreno et al., 2001). For example, Dede, Salzman, Loftin, and Ash (2000, p. 368) call for research investigating whether “the virtual reality medium is a better (or a worse) teaching tool than other pedagogic approaches.” Similarly, Seidel and Chatelier (1997, p. 2) call for research comparing how people learn from desktop workstations versus from HMDs by asking, “What is the value added by HMD, and what purposes or what types of tasks does it serve best for learning purposes?”

Did Media Affect Learning in the Design-A-Plant Environment?

The present study yields evidence—based on questionnaires—that students feel a stronger sense of presence in more immersive VREs. In addition, our study provides new evidence—from retention tests, transfer tests, and program ratings—that students who learn in a more immersive VRE do not necessarily learn a computer-based lesson more deeply as compared with students who learn in a less immersive VRE. Thus, the findings failed to support a medium-helps-learning hypothesis or a medium-hurts-learning hypothesis.

Students’ ratings of presence for Experiment 1 and to a less extent for Experiment 2 were overall low. The immersion level was manipulated by providing some students with HMDs, but the VREs themselves were not very compelling. The environments and plants consisted of computer-generated graphics. Therefore, the lack of media effects on retention, transfer, and program ratings might be explained as a consequence of the limitations of the specific VREs designed for the Design-A-Plant program. Had the program’s interface been more natural or transparent, learning in more immersive conditions might have played a fundamental role in learning (Norman, 1990).

Did Method Affect Learning in the Design-A-Plant Environment?

This research provides one of the first methodologically rigorous studies of conditions that foster productive learning in a virtual environment. As predicted by a learner-centered approach to instructional design, VREs for learning that are designed in light of how the human mind works are more likely to lead to meaningful learning than those that are not. This hypothesis was supported by the finding of a modality effect for retention, transfer, and program ratings across different media in two experiments.

The replication of the modality effect across different media shows that effective learning depends on which instructional techniques help guide the learner’s cognitive processing of the presented material rather than on the medium per se. More important, our research has shown that the same factors that improve student understanding in one medium (such as modality effects in a desktop environment) improve student understanding in another medium (such as modality effects in an HMD environment). In both cases, ineffective instructional messages can be converted into effective ones by applying the same instructional design principles (Fleming & Levie, 1993).

Did Media Enable Method in the Design-A-Plant Environment?

There was no consistent evidence that applying good design principles was more effective in one medium than another, and hence no support in this study for the media-enables-method view. Apparently, the methods we used—such as the use of narration rather than text—were supported equally well in the high- and low-immersion environments we chose to study. However, the media-enables-method view is somewhat supported by our earlier finding that students learn better from a computer-based game-like method than from a book-like presentation of the same material as text and illustrations (Moreno et al., 2001). In short, the game-like environment is supported by computer-based media but not by book-based media.

Limitations and Future Directions

To date, there has been very little research on the educational value of VREs (McLellan, 1996). Therefore, in assessing the instructional value of this technology, we recommend keeping in mind that it is at a very early stage of development. The conclusions we have drawn are limited by the nature of the learning materials, by participants’ familiarity with the technology, and by the quality of the VR experiences. The learning materials consisted of an environmental science VRE with short agent and student interventions. It is possible that in VREs where students’ physical interventions are essential to the learning process, such as if the goal of the instructional material is to train a procedure, the use of more immersive environments might play an important role in adding psychomotor feedback to the learning experience (Seidel & Chatelier, 1997; Thurman & Russo, 2000). Because some media may enable instructional methods that are not possible with other media, it might be useful to explore instructional methods that are possible in immersive environments but not in others. In the future, it is more likely to expect learning differences as a function of immersion as people gain familiarity with these newer technologies. More research is needed to explore the circumstances under which presence may enhance learning.

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