Animation as Feedback in a Computer-Based Simulation: Representation Matters

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The purpose of this study was to explore how users interact and learn during a computer-based simulation given graphical and textual forms of feedback. In two experiments, university students interacted with a simple simulation that modeled the relationship between acceleration and velocity. Subjects interacted with the computer simulation using a discovery-based approach: no formal instruction on the science concepts was presented. Subjects had control over the acceleration of a simple screen object—a ball—in a game-like context. Three simulation conditions were studied, each differing on how feedback of the ball's speed, direction, and position was represented: graphical feedback, textual feedback, and graphical plus textual feedback. Results showed that subjects learned more tacit knowledge when provided with animated graphical feedback than with textual feedback, although gains in explicit understanding of these science principles did not depend on the way the feedback was represented. Patterns of interactivity and frustration are also discussed.

☐ In recent years, the data processing capabilities of desktop computers have increased dramatically and the graphical-user interface (GUI) has gained wide acceptance. One result of these two trends has been the ability to provide an almost unlimited assortment of highly visual and interactive learning environments on desktop computers. Of course, along with this comes the rather ironic problem of how best to harness these capabilities in the instructional design process. This seems especially true as learning environments become more interactive and complex, such as in the case of educational simulations.

Designing effective interfaces for educational simulations and other forms of multimedia is a formidable task (Schneiderman, 1987). There are three major design components to an educational simulation: the underlying model, the simulation's scenario, and the instructional overlay (Reigeluth & Schwartz, 1989). The underlying model refers to the mathematical relationships of the phenomenon being simulated. The scenario and instructional overlay refer to the context of the simulation. The scenario presents the simulation in some contrived situation (either real or imaginary). The instructional overlay includes any features, options, or information embedded in the simulation to help the user explicitly identify and learn the relationships being modeled in the simulation. The structure and scope of the instructional overlay depend in large part on the instructional approach and purpose of the simulation. A simulation used in a more traditional role as follow-up practice to a tutorial would contain a more elaborate instructional overlay than a simulation in a discovery-based approach (Alessi & Trollip, 1991;

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Joolingen, 1991; Towne, 1995; Towne, Jong & Spada, 1993).

Obviously, when simulations are designed for educational applications, users must be able to tell the difference between their goals and intentions and the range of allowable actions (Norman, 1988, p. 51, referred to this as the "gulf of execution"). Users must also be in a position to evaluate effectively whether their expectations and intentions have actually been met, and if not, why (Norman, 1988, p. 51, referred to this as the "gulf of evaluation"). For this reason, feedback is arguably one of the most important attributes of a simulation's interface. In contrast to the traditional behavioral view of feedback playing the roles of reinforcer and motivator, most current theories of learning stress the information that feedback provides to learners, especially in response to errors (Kulhavy & Wager, 1993). Rather than something to be avoided, errors are a valuable part of the learning process, especially during discovery-based, or inductive, learning. Learners must be able to isolate, select, and manipulate each of the relevant variables in a given domain in order to test and revise hypotheses about the domain (Mayer, 1983, 1989). The way in which a simulation provides feedback to the user is critical. In designing a simulation's interface, designers must decide whether to use visual (i.e., graphics), verbal (i.e., text or speech), or aural (i.e., sound) feedback, or some combination.

There is a large body of research demonstrating that the way information is represented matters greatly in the learning process, at least for memory tasks. In general, research indicates that pictures are superior to words for remembering concrete concepts. Although competing theories exist (such as propositional theories), Paivio's dual coding theory is the most established and the most empirically validated (Paivio, 1990, 1991; Paivio & Csapo, 1973). This theory suggests a model of human cognition divided into two dominant processing systems—one verbal and one nonverbal. The verbal system specializes in linguistic or "language-like" processing. The nonverbal (hereafter called visual) system concerns the processing of visual information, although Paivio contends that it also accounts for the memory of *all* nonverbal phenomenon, such as emotional reactions.

Dual coding theory predicts that words and pictures provided by instruction will activate these coding systems in different ways. Dual coding theory explains the picture superiority effect on the basis of two important assumptions (Kobayashi, 1986). First, it is believed that the verbal and visual codes produce additive effects. That is, if information is coded both verbally and visually, the chances of retrieval are doubled. The second assumption is that words and pictures activate mental processing in very different ways. Simply put, pictures are believed to be far more likely to be coded both visually and verbally, whereas words are believed to be far less likely to be coded visually. Although Paivio's dual coding theory has been extensively applied to the role of visuals in illustrating printed text, it also holds promise in guiding research with computer-based multimedia learning environments (Mayer & Anderson, 1992a, 1992b; Mayer & Sims, 1994).

Dual coding theory also predicts that three distinctive levels of processing can occur within and between the verbal and visual systems: representational, associative, and referential (Paivio, 1990). Representational processing describes the connections between incoming stimuli from the environment and either the verbal and visual system. Associative processing refers to the activation of informational units within either of the verbal or visual systems, whereas referential processing is the building of connections between the verbal and visual systems. It is hypothesized that interactive forms of multimedia, such as computer simulations, will promote different levels of processing depending on the type of representation used (e.g., text, graphic, animation, sound) and the purpose (e.g., establishing the scenario, providing feedback between the user's actions and the effects on the underlying model, or instructional messages to help make the relationships of the simulation more explicit). For example, simulations modeling physical processes in real time, such as principles from physics, may actually interfere with referential processing if the simulation does not provide adequate opportunity for student reflection and hypothesis testing.

Feedback, whether visual or verbal, is provided to the user in a simulation in real time—the feedback changes as fast as the user inputs data. The simulation generates the feedback based on the input of the user in tandem with the mathematical model. When the simulation models a physical science phenomenon, such as Newtonian mechanics, the computer must process data and display feedback so as to precisely match the motion of objects in the real world. For example, a simulation meant to demonstrate the change in speed over time of the free-fall movement of a dropped ball given earth's gravity must carefully coincide with data from the real world. Simulations that rely on computer graphics to represent physical science principles, or any phenomena involving the motion of objects, require the computer to produce *animated* visuals in real time.

In contrast to static computer graphics, animated computer graphics can provide users with additional information through two important visual attributes: motion and trajectory (Rieber & Kini, 1991). Animation can provide concrete visual information about whether or not an object is moving, as well as whether the object's motion is changing over time, such as speeding up or slowing down. Animation can also provide information about the direction in which an object is moving (i.e., trajectory), such as toward the left, right, top or bottom. The efficacy of animated displays should be greater when both attributes contribute to the task than when only one of the two (motion or trajectory) is required.

On the other hand, animation's capability to represent information and relationships in ways that closely resemble natural phenomena may not make the information and relationships explicit. That is, learning from animation may remain implicit or tacit unless the learner makes a deliberate attempt to formalize the relationships or unless these relationships are made explicit for the learner through external intervention, such as instruction. When such relationships are explicitly known to the learner, animation should increase the depth and fluency of learning when the task requires the active visualization of relevant information, concepts, or relationships that change in some way over time. However, the conditions under which animation may help or hinder such transformations from tacit to explicit understanding remain open to question.

A small, but important pool of research has been conducted to understand the role of animation used as part of explanatory presentations (Mayer & Anderson, 1992a, 1992b; Rieber, 1990, 1991). However, how learners select, process, and interpret the real-time feedback provided by animation in a computer simulation is not well understood (Alessi & Trollip, 1991; Duchastel, 1990–1991). Although some initial research has indicated that visually-based simulations can be an effective learning strategy (Gorrell, 1992; Reigeluth & Schwartz, 1989; Rieber, 1990; Rieber, Boyce & Assad, 1990; Tennyson, Thurlow & Breuer, 1987), further research is needed to better understand the specific role of real-time graphic feedback versus textual feedback. The way in which a learner uses this feedback is particularly crucial when simulations are part of discovery-based learning environments, such as simulations and microworlds. If feedback does not match the cognitive and affective needs of students as they interact with a simulation with limited guidance, students may be unwilling or unable to take the necessary steps or invest sufficient effort to either adequately explore the simulation's parameters or seek other sources of guidance, such as a tutorial or teacher.

Oftentimes, instruction may favor one kind of stimulus (visual or verbal) even though learners, especially novices, may benefit more from the other. For example, much science instruction is often taught in highly abstract ways so as to promote the underlying mathematics of the phenomena being studied, even though students may not adequately grasp essential concrete concepts or principles (diSessa, 1993; White, 1993). A particularly good example is the relationship between acceleration and velocity, a common principle in introductory physics classes. Instruction usually focuses on the mathematical relationship between acceleration and velocity instead of building a strong conceptual understanding of the principle. Consequently, students typically spend considerable time studying and applying formulas, even though a concrete understanding of the principle may be missing or muddled (Roschelle, 1991; Roschelle & Greeno, 1987).

The purpose of this study was to explore questions about the role of computer animation as real-time graphic feedback during a simulation. A variety of data sources were used in this study. Some were traditional performance measures, such as pretests and posttests to study subjects' formal learning of the concepts and principles. In addition, alternative methods of evaluating subjects' learning and patterns of interactivity were included. Subjects were asked to complete all of the simulation trials using a simple game context. Because an understanding of the relationship between acceleration and velocity was necessary to be successful at the game, the game score provided an interesting alternative and comparison to the pretest/posttest as a measure of performance. Whereas the posttest was considered to be an explicit measure of subjects' understanding of the science principles, the game score provided an implicit, or tacit, measure. Cognitive theories of learning also emphasize the qualitative nature of interactivity in learning. Learning is not simply determined by the amount of surface level interactivity in a learning task, but is a function of how meaningful the feedback is to the learner. More feedback will not necessarily result in more knowledge or understanding. Similarly, undue frustration may interfere with potentially meaningful feedback. Therefore, data related to subjects' level of overt interactivity during the simulation and self-reported levels of frustration were also collected in order to study these relationships.

In this study, subjects' patterns of interactivity with a simple computer simulation of the relationship between acceleration and velocity were investigated. Subjects were given control over the acceleration of a screen object (an animated ball) and were then able to observe the resulting effects on the object's velocity. The feedback generated by the simulation was a direct result of their interaction, similar to that of a video game. Of most interest was how learners processed real-time feedback when presented in either textual form (e.g., numeric display of the ball's screen position) or graphical form (e.g., an animated display of the ball).

Given the subject matter of the simulation (acceleration and velocity) and the nature of the task embedded in the simulation (controlling the motion of a computer-generated object in a gaming activity), it seems logical that actually providing an animated graphic of the ball should be a better feedback representation than a textual description of the ball's motion. Therefore, it was hypothesized that subjects would perform better at the game when the feedback was graphical rather than textual. However, it was also hypothesized that success at the game would rely on implicit or experiential knowledge. Therefore, it was unclear whether subjects given graphical feedback would likewise be better able to demonstrate an explicit understanding of the motion principles required on a traditional performance test. Textual feedback during the game may be a better approach to achieving such explicit learning outcomes. Textual feedback would force subjects to *mentally* transform the numerical information into visual form. Such a mental transformation should help to make the underlying mathematical model of the simulation more apparent. Of course, subjects may be unwilling to invest the considerable mental effort required for such a transformation. It could be argued that providing subjects with *both* graphical and textual feedback would be the best approach because it would allow subjects to switch between the two representations as needed. However, if subjects are unable to appropriately select and then focus attention on one representation while ignoring the other, the combination of feedback types would be distractive. This study was designed to provide insight into these questions.

EXPERIMENT 1

Method

Subjects. Subjects were 40 upper-class undergraduate students (juniors and seniors) enrolled in an introductory computer education course. Participation was voluntary, although extra credit in the course was provided to students as incentive to participate. Fourteen subjects served in the graphical feedback group, 12 served in the textual feedback group, and 14 served in the graphical plus textual feedback group.

Materials. The materials consisted of the three versions of a computer-based simulation of the relationship between acceleration and velocity. Velocity is the speed and direction of an object and acceleration is the rate of change of the velocity of an object over time. Subjects had direct control over the acceleration of a simple computer-generated object in the simulation—a ball. In Experiment 1, subjects were given a total of 10 trials with the simulation.

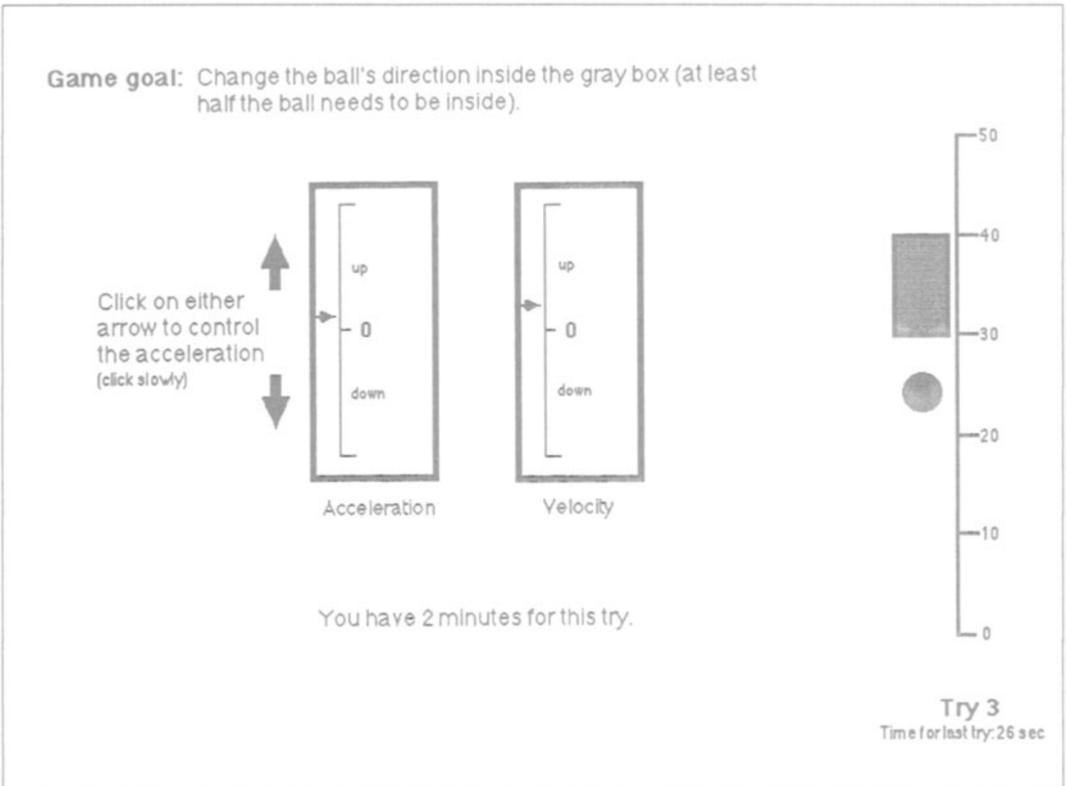
In all 10 trials of all three versions, the ball moved in one dimension only (vertically). Each trial began with the ball in constant, nonzero velocity (see Figure 1). One trial would begin, for example, with the ball moving from the bottom to the top at a constant speed of about 3 centimeters (cm) per second.[1] Subjects were able to change only the acceleration of the ball by clicking on either an Accelerate Up button or Accelerate Down button, though they could click on these buttons as often as they wished. The buttons were in the shape of large up and down arrows. Each time the subject clicked on either acceleration button (up or down), the computer added one unit of acceleration to the ball's motion in that direction. For example, if the subject clicked just once on the up arrow, the simulation would record the object's acceleration as .1 cm per second per second to the top. Consequently, the velocity of the object already moving at 3 cm per second from bottom to top would begin to increase its speed by .1 cm every second: after 1 second its speed would be 3.1 cm per second; after 2 seconds its speed would be 3.2 cm per second, and so forth. If the subject pressed the up arrow again, another unit of acceleration would be added to the ball. The ball would increase in speed by .2 cm per second per second—the rate of change in the ball's speed would be doubled. In this example, the ball's speed would continue to increase in speed unless the subject clicked on the down arrow twice to return the acceleration to 0, at which point the ball would continue to move again at a constant velocity. To make the ball slow down, the subject would need to press the down arrow which would record the object's acceleration as .1 cm per second *to the bottom.* For example, if the object was moving at a velocity of 5 cm per second in a bottom to top direction, the object's speed would decrease in speed by .1 cm every second until its speed reached zero, at which point the object would reverse direction and begin moving from top to bottom with its speed then *increasing* at a constant rate of .1 cm per second.[2] All subjects were given explicit directions on how to work the simulation as well as two practice trials after which they were encouraged to ask for help if they were confused. All subjects seemed to understand the directions of the simulation.

The task for all subjects in all versions was to try to understand the relationship between acceleration and velocity through their interac-

1 Please note that standard units of measurement (i.e., centimeters and seconds) are being used here to help the reader understand the nature of the simulation activity even though there was no attempt to calibrate the simulation to these standards. The speed of the animated object was based on units of distance and time that were unique to the simulations. For example, distance was measured in pixels and time measured in simulation cycles. Of course, all units of measurement are arbitrary conventions and the actual choices for these units do not matter so long as they remain consistent.

2. Obviously, an adequate understanding of the relationship between acceleration and velocity is prerequisite to fully understanding the nature of the task that subjects experienced in this study. An adequate explanation of the underlying physics principles is beyond the scope of this article. Unfortunately, the static medium of a journal article does a poor job of representing such a dynamic system.

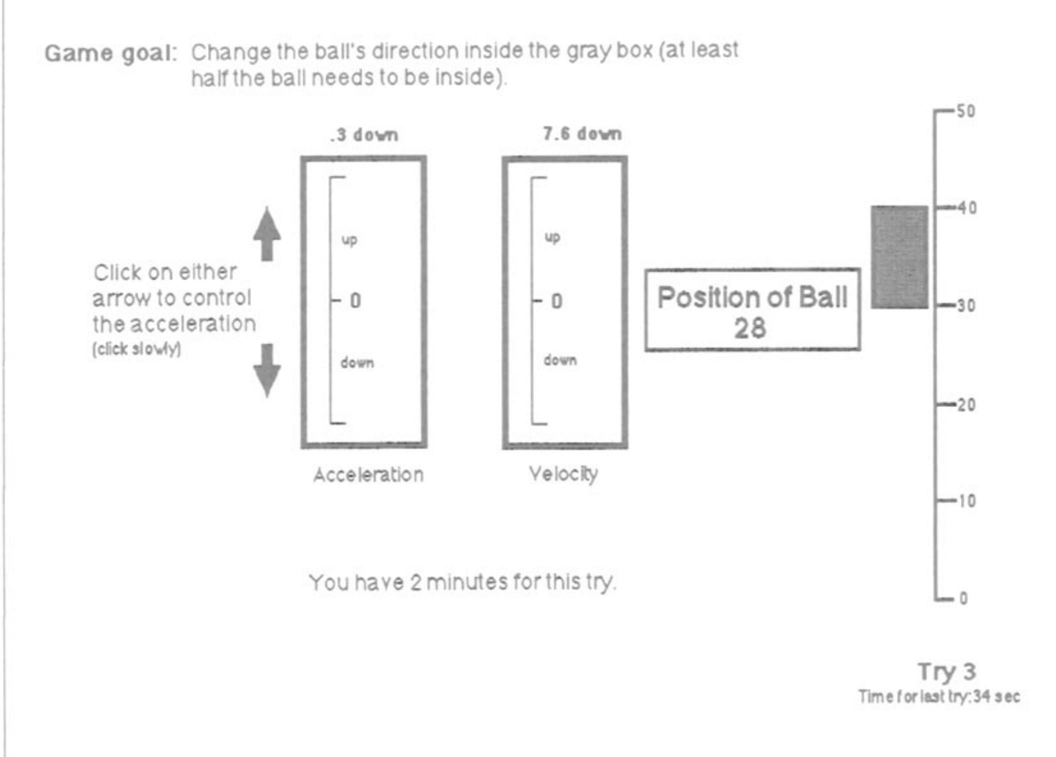
Figure 1 ☐ Snapshot of the computer screen during the simulation in which graphical feedback was provided. Feedback about the ball's acceleration, velocity, and position was displayed by animating the ball on the computer screen.



tion with the simulation. As previously stated, there was no instructional overlay (i.e., special instructional features, options, etc.)—subjects were required to use a discovery-based approach to learning. However, all three simulation versions were presented in a game-like context. In each trial, subjects were given the goal of changing the direction of the ball's motion (i.e., make it do a flip flop) when it was inside the area indicated by a gray box, or in other words, when the ball was between 30 and 40 on the number line (as illustrated in Figures 1 and 2). This context provided a unique opportunity to collect an important source of data—subjects' scores on the gaming activity. Each trial began with the ball already in motion, although the initial speed and direction of the ball was different in every trial (though not randomly generated; the different initial conditions of each trial were predetermined and given to all subjects in the same sequence). The gray box was always located between the 30 and 40 on the number line.

The computer computed the resulting velocity (i.e., speed and direction) and position of the ball and reported this information back to the user in real time, that is, the computer updated the velocity of the ball as fast as the user interacted with the simulation. In the graphical feedback version of the simulation, subjects saw and had control over an animated graphic of the ball moving on the computer screen and animated arrows detailing the velocity (speed and direction) and acceleration (rate of change in velocity and direction) of the ball, as illustrated in Figure 1. The textual feedback version, on the other hand, consisted only of a numeric readout of the same information, as illustrated in Figure 2. The graphical plus textual version of the simulation

Figure 2 ☐ Snapshot of the computer screen during the simulation in which textual feedback was provided. Feedback about the ball's acceleration, velocity, and position was displayed only in numerical form.



provided both feedback representations to the subjects.

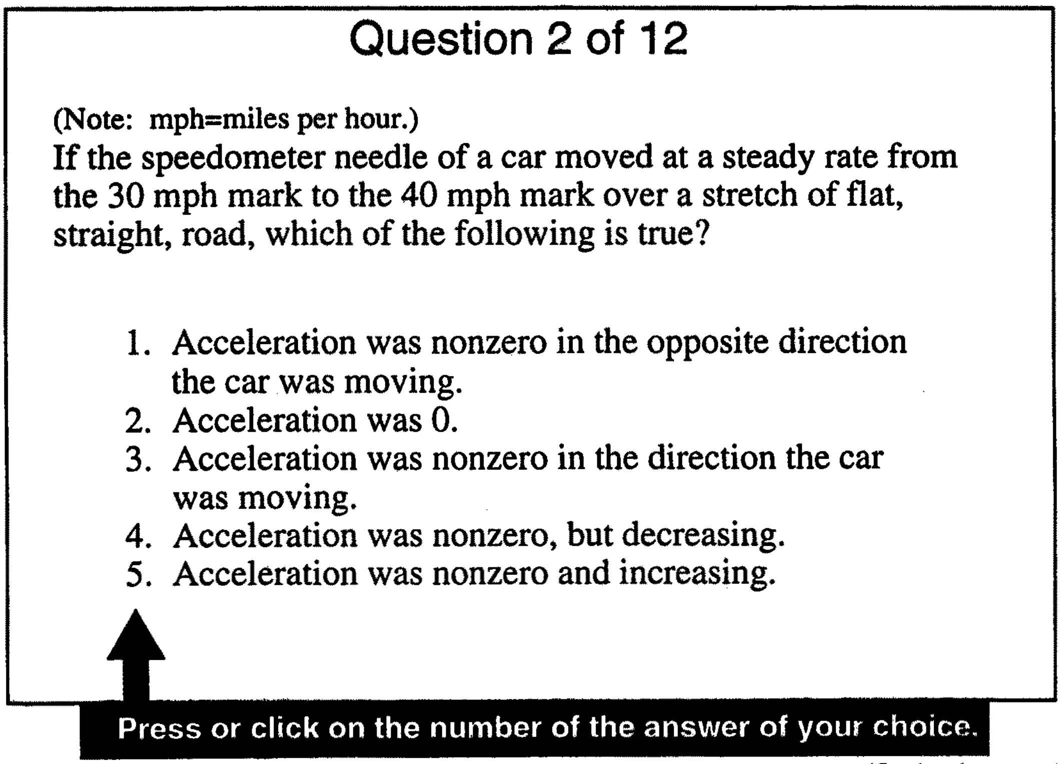
Dependent Measures

Performance test. A 12-item test was used to measure subjects' understanding of the relationship between acceleration and velocity. This measure corresponds to rule using as defined by Gagné (1985). Multiple-choice questions (1 answer and 4 distractors) were used as the testing format. The test was given to subjects immediately before (pretest) and after (posttest) the simulation trials in both experiments. KR-20 reliability for posttest was .66 in Experiment 1 and .57 for Experiment 2. Representative questions are shown in Figure 3 (see pp. 12 and 13).

Game score. The time, in seconds, taken by subjects to complete the game successfully was used as a scoring feature. The number of seconds elapsed at the moment the subject successfully completed the game was used as the subject's score for that trial. There was a time limit of two minutes for each trial. If the clock exceeded the time limit before the subject successfully completed the game, the computer automatically ended the simulation and the subject was given a score of 120 for that trial. The lower the game score, the better the subjects' performance in the game. After each trial, subjects were prompted to try to improve their score on the next trial.

Interactivity. The total number of times subjects clicked either the Accelerate Up button or Accelerate Down button during each simulation was recorded by the computer. This

Figure 3 □ Two representative questions from the pretest/posttest. (The orrect answer to the top question is 3 and the correct answer to the bottom question is 2.



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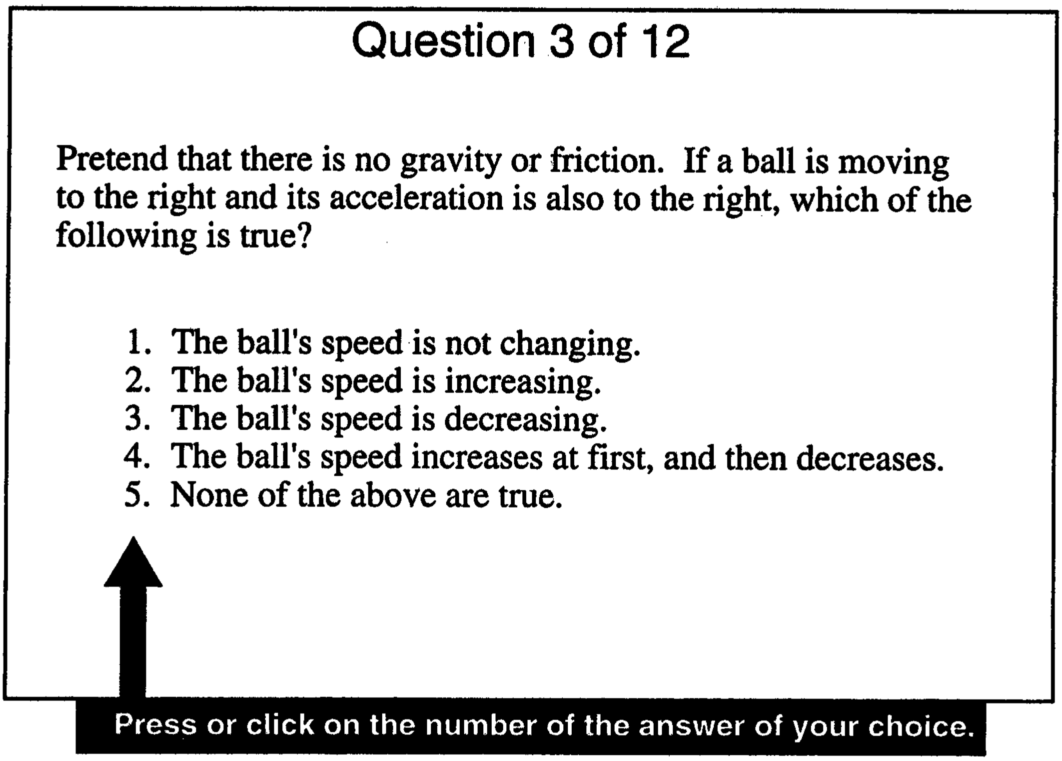
counter was automatically reset to 0 at the start of each simulation trial. As previously described, the pressing of either the up or down accelerate button was processed by the simulation's underlying mathematical model which, in turn, caused a change in the motion of the ball. This variable is a simple measure of subjects' overt interactivity during the simulation as it is the only means by which they could manipulate the motion of the ball. There are many interpretations about what differences in this measure might mean. On one hand, those subjects who are not improving their understanding of the relationship of acceleration and velocity may show an increase in their clicking behavior due to a frantic attempt to make sense of the activity. Others may simply choose to ignore the activity and wait for the time to expire, thus showing relatively low levels of interactivity. By including this measure in this study, it was possible to compare the patterns of interactivity with performance and self-reports of frustration.

Frustration. After each of the 10 simulation trials, subjects were asked to rate their level of frustration. The computer displayed a message box titled "Self-evaluation of frustration" with the directions to "Please rate your frustration level at this point on the following scale from 1 to 9." The scale consisted of nine buttons numbered 1 to 9 with the words no frustration printed left of button 1, extreme frustration printed right of button 9, and neutral printed under button 5. Analysis of subjects' frustration was based on the sum of these 10 self-reports.

Procedures

Subjects were randomly assigned to one of the three feedback conditions as they reported to the computer lab. They were given a general orientation to the procedures of the experiment. They were told that their goal was to try

Figure 3 ☐ *(Continued.)*



to learn as much as they could about the relationship between acceleration and velocity through their experiences with the simulation. All of the simulations and testing were administered by computer. Once instructed to begin, subjects worked individually with the computer. Before providing subjects with any experience with the simulation, the computer immediately administered the 12-item pretest. Subjects then were given two practice trials with the simulation. The practice trials provided both graphical and textual feedback in order to ensure that subjects clearly understood the nature of the task. Subjects were then given 10 trials with their respective version of the simulation. Immediately upon completion of the simulation activities, the computer automatically administered the posttest consisting of the same 12 multiple-choice items. Approximately one hour was needed to complete the experiment.

Design and Data Analysis

Performance was analyzed using an unbalanced mixed design analysis of variance (ANOVA): 3 levels of the between-subjects factor Feedback (Graphics, Text, Graphics plus Text) were crossed with 2 levels of the within-subjects factor Performance (Pretest, Posttest). In addition, separate ANOVAs were conducted on the game score, interactivity, and frustration variables.

Results

Performance test. Percent means and standard deviations of subjects' pretest and posttest scores are contained in Table 1. No significant differences were found between any of the three simulation versions, $F(2,37) = .256$, $p = .78$, $MS_{error} = 761.88$. Students performed similarly regardless of how the simulation's feed-

Table 1 □ Mean Percentage Scores and Standard Deviations for Performance for Experiment 1

Feedback		*Performance*	
		Pretest	*Posttest*
Graphical	*M*	53.0	64.3
SD	20.3	21.5	
n	14	14	
Textual	*M*	51.8	56.0
SD	19.7	28.4	
n	14	14	
Graphical plus Textual	*M*	51.4	56.9
SD	13.7	15.4	
n	12	12	

back was represented. However, there was a significant difference overall in subjects' pretest and posttest scores, $F(1,37) = 10.98$, $p < .005$, $MS_{error} = 91.39$. In general, subjects increased their formal understanding of the relationship between acceleration and velocity as a result of interacting with the simulation in a discovery-based approach (pretest mean = 52.1% and posttest mean = 59.2%). No interaction was detected between the pretest/posttest and the three simulations versions, $F(2,37) = .1.086$, $p = .35$, $MS_{error} = 91.39$.

Game Score. Means of the subjects' game scores for each of the 10 simulation trials are graphed in Figure 4. A significant difference was found between the simulation versions on subjects' game scores, $F(2,37) = 5.4$, $p < .01$, $MS_{error} = 533195.11$. Follow-up multiple comparisons on the means using Fisher's least significant difference (LSD) method showed that game scores were significantly lower (i.e., better) when the simulation provided subjects with graphical feedback (mean = 401.9 seconds) than when given textual feedback (mean = 628.1 seconds). No differences were found between the graphical feedback version and the graphical plus textual feedback version (mean = 515.2 seconds). Likewise, no differences were found between the textual feedback and graphical plus textual feedback versions.

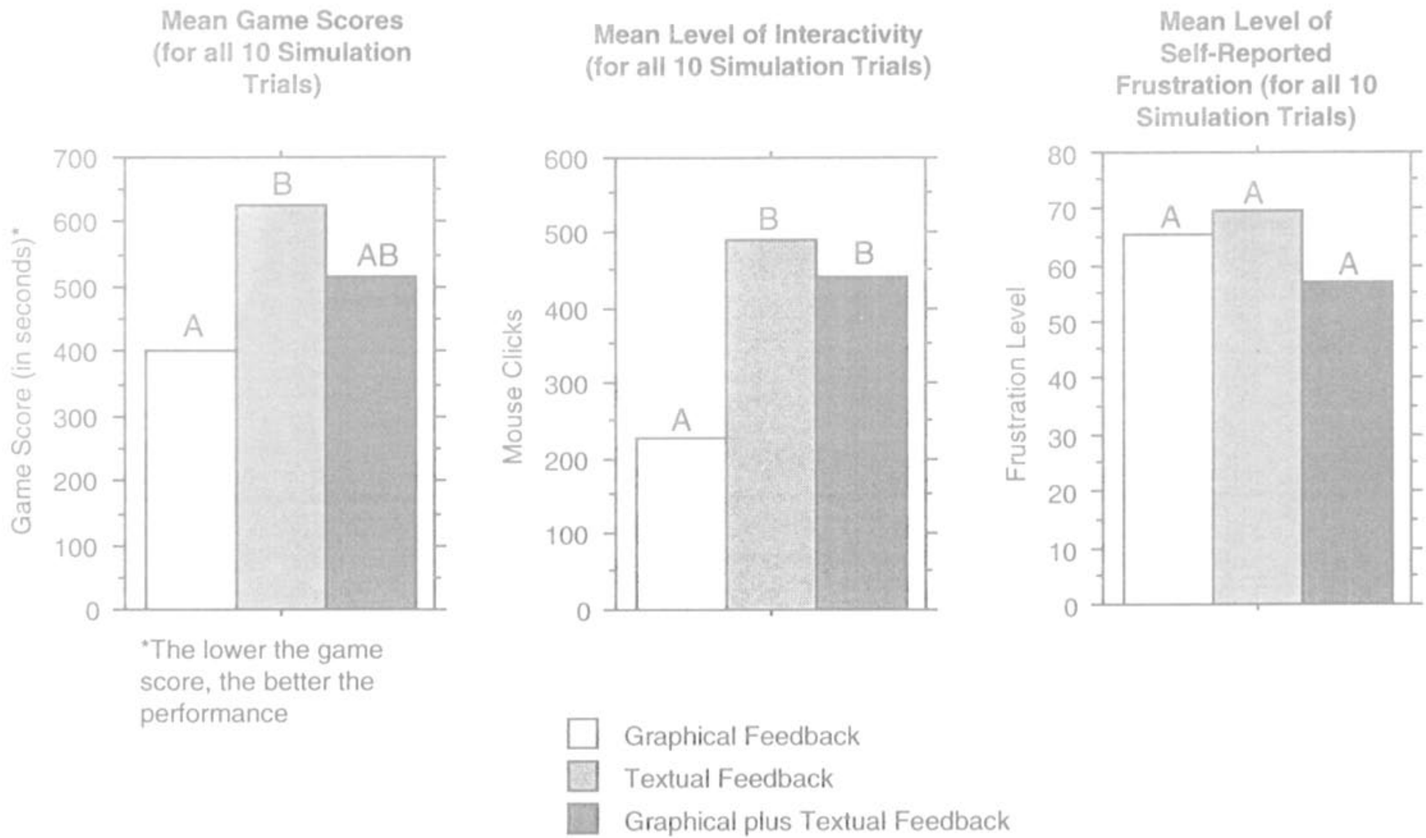
Interactivity. Means of the subjects' level of interactivity for each of the simulation versions are contained in Figure 4. A significant difference was found between the simulation versions on subjects' level of interactivity within the simulation, $F(2,37) = 5.7$, $p < .01$, $MS_{error} = 47465.08$. Follow-up multiple comparisons on the means using Fisher's LSD method showed that subjects' level of interactivity was significantly lower when the simulation provided subjects with graphical feedback (mean = 229.4 mouse clicks) as compared to when subjects were provided with either textual feedback (mean = 492.8 mouse clicks) or graphical plus textual feedback (mean = 441.8 mouse clicks). There was no difference in the level of interactivity between the textual feedback and the graphical plus textual feedback versions.

Frustration. No significant differences were found between any of the simulation versions on frustration, $F(2,37) = 1.4$, $p = .26$, $MS_{error} = 363.5$. Subjects' level of self-reported frustration did not vary significantly based on the type of feedback provided in the simulation version (means are graphed in Figure 4).

DISCUSSION

The results from Experiment 1 support the idea that the way in which feedback is represented in a computer-based simulation influences learning in a discovery-based approach. Subjects were most successful at the accelera-

Figure 4 □ Means of subjects' game scores, level of interactivity, and frustration levels for the three simulation groups: Experiment 1.



Note: Same letter indicates no significant differences

tion/velocity game when the feedback was represented graphically with real-time animation. Patterns of interactivity were likewise differentiated on the basis of feedback—less, not more, interactivity seemed to relate to greater game performance, suggesting that graphical feedback provided a different level of information for the quick decision-making required to be successful at the game. However, the fact that subjects' learning on the performance test did not differ on the basis of the feedback provided suggests that this feedback mattered only at a tacit level of understanding required in playing the game.

Tacit knowledge is usually defined as knowledge of which we are generally unaware and which remains unanalyzed by the individual (Alexander, Schallert, & Hare, 1991). The acquisition of tacit knowledge "takes place largely independently of conscious attempts to learn and largely in the absence of explicit knowledge about what was acquired" (Reber, 1993, p. 5). The learning of tacit knowledge is considered to be a natural, automatic process occurring at an unconscious level (Reber & Lewis, 1977). The simulation activity modeled the natural phenomenon of the acceleration and velocity of an object in real time, thus providing subjects with a continual stream of feedback to interpret. Not surprisingly, subjects given graphical feedback were in a much better position to process and interpret these data to successfully complete the game than subjects given textual feedback. The cognitive load for subjects given textual feedback was considerable and this significantly affected their game scores. From a dual coding perspective, subjects given graphical feedback were more able to activate meaningful representational and associative processing of the simulation's feedback than subjects given only textual feedback.

Despite the better game scores by subjects given graphical feedback, their performance on the pretest/posttest indicate that they were no better able to transfer their understanding from the simulation to an explicit test of the principles than subjects in the other two treatment conditions. The performance measure (pretest/posttest) was predominantly verbal in nature and required a formal understanding of the physical principles at work. From a dual coding perspective, improvement from the pretest to the posttest would require referential processing between the visual and verbal systems. The performance data indicate that referential processing was facilitated in similar ways by all three simulation conditions, though learning gains were clearly not impressive.

EXPERIMENT 2

A possible confound in Experiment 1 is that subjects simply may not have had sufficient exposure and experience with the simulation for other effects to be noticed. Experiment 2 was designed to solve this problem by doubling subjects' exposure to the simulation from 10 trials to 20 trials.

Method

Subjects, design, and data analysis. The subjects were 49 upper-class undergraduate students (juniors and seniors) enrolled in an introductory computer education course. Participation was again voluntary with extra credit in the course provided to students as incentive to participate. Fifteen subjects were randomly assigned to the Graphical Feedback group, 16 subjects to the Textual Feedback group, and 18 subjects to the Graphical plus Textual Feedback group. As in Experiment 1, performance data were analyzed using a mixed design ANOVA, whereas separate ANOVAs were conducted on the game score, interactivity, and frustration variables.

Materials and procedure. All materials and dependent measures were identical to those used in Experiment 1. The only change in Experiment 2 was that subjects were given a total of 20 trials (instead of 10) in the respective simulation version to which they were randomly assigned.

Table 2 ☐ Mean Percentage Scores and Standard Deviations for Performance for Experiment 2

		Performance	
Feedback		*Pretest*	*Posttest*
Graphical	*M*	44.0	55.0
SD	18.8	20.1	
n	15	15	
Textual	*M*	34.4	35.4
SD	14.2	15.1	
n	16	16	
Graphical plus Textual	*M*	42.6	46.8
SD	14.5	21.2	
n	18	18	

Results and Discussion

Performance Test. Percent means and standard deviations of student pretest and posttest scores are contained in Table 2. In contrast to the results from Experiment 1, significant differences were found between the three simulation versions on the performance test, $F(2,46) = 3.46$, $p < .05$, $MS_{error} = 499.02$. Follow-up multiple comparisons on the means using Fisher's LSD method indicated that students provided with graphical feedback or graphical plus textual feedback scored significantly higher overall on the performance test (pretest and posttest combined) than subjects provided only with textual feedback. However, this result is not of interest because subjects randomly assigned to the textual feedback condition scored unusually low on the pretest.[3] No interaction was detected between the performance test and the three simulations versions, $F(2,46) = 1.768$, $p = .18$, $MS_{error} = 115.93$. Scores on the performance test did not depend on the feedback condition.

Also, similar to Experiment 1, there was a significant difference overall in subjects' pretest and posttest scores, $F(1,46) = 5.87$, $p < .05$, $MS_{error} = 115.93$. In general, subjects again increased their formal understanding of the relationship between acceleration and velocity as a result of interacting with the simulation in a discovery-based approach (pretest mean = 40.3% and posttest mean = 45.6%), though again the learning gains were not impressive.

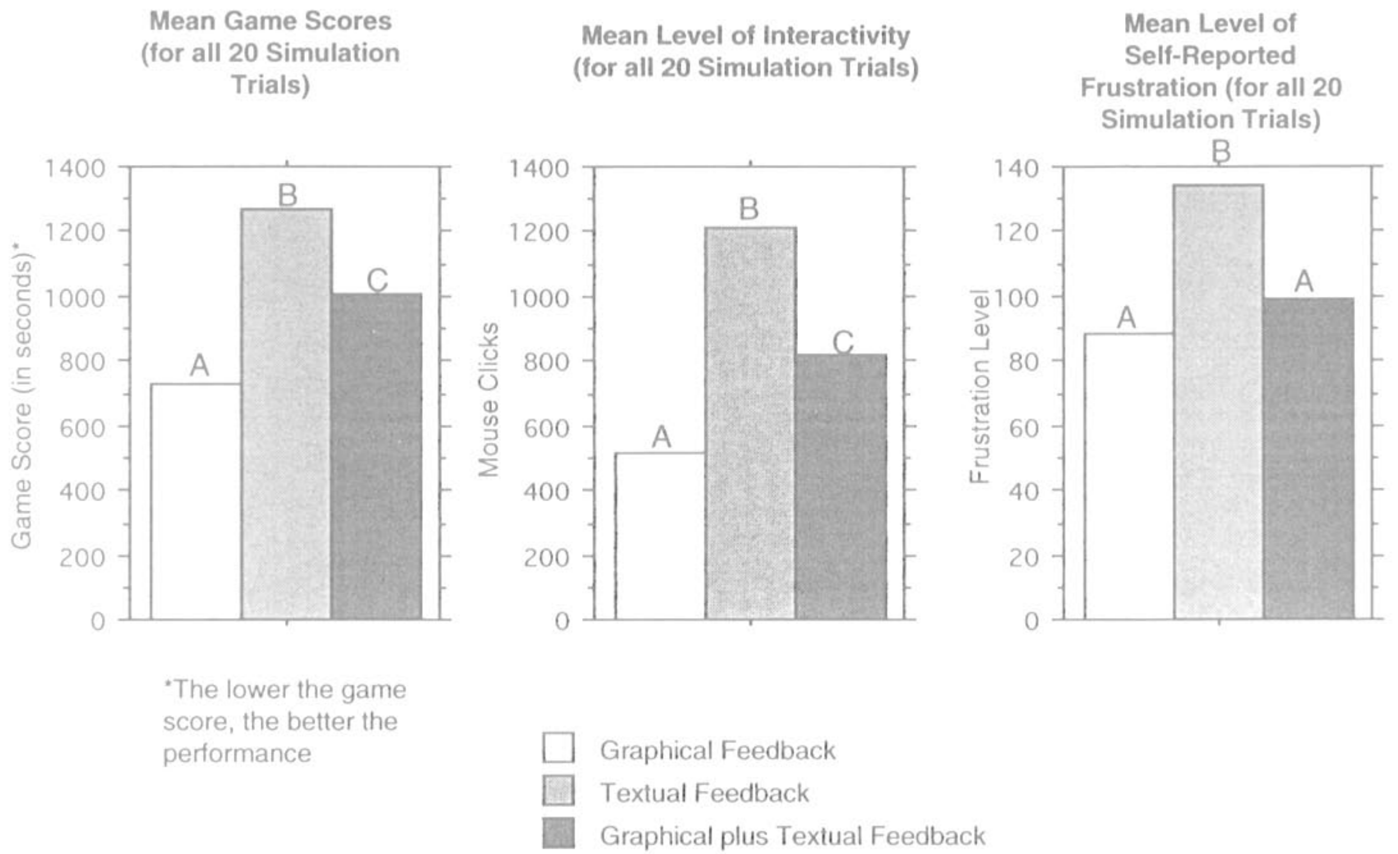
Game Score. Means of the subjects' game scores for each of the 20 simulation trials are graphed in Figure 5. A strong significant dif-

3 Table 2 indicates that subjects in the textual feedback group scored 9.6 percentage points lower on the pretest than subjects in the graphical feedback group and 8.2 percentage points lower than subjects in the graphical plus textual feedback group, despite the fact that procedures for random assignment were strictly observed in experiment 2. This difference is a cause for concern. It is believed that this difference is a function of sampling fluctuation, exacerbated by the relatively small number of subjects in each treatment. Fortunately, the results from the mixed design ANOVA are based on differences between the pretest and posttest means of each of the three groups, therefore this difference on the pretest and posttest means of each of the three groups is taken into account in the results and conclusions.

One reviewer suggested that the performance data (pretest/posttest) be analyzed using an analysis of covariance (ANCOVA) with the pretest used as the covariate. An ANCOVA is not the preferred analysis here for three reasons: there are fewer assumptions to be met with a mixed design ANOVA; ANCOVA does not allow interactions between the within-subjects factors and the between-subjects factors to be studied; and in most cases an ANCOVA does not offer as much statistical power as a mixed design ANCOVA (Glass & Hopkins, 1984; Myers, 1979).

It is also important to note that subjects in Experiment 1 generally scored higher on the pretest than subjects in Experiment 2. Reasons for this are unclear. Experiment 2 was conducted approximately 15 weeks after Experiment 1. Subjects in Experiment 2 were drawn from the same undergraduate education course, but in the subsequent academic quarter. Despite these differences, it is believed that the subjects in both experiments should still be considered as samples from the same population.

Figure 5 □ Means of subjects' game scores, level of interactivity, and frustration levels for the three simulation groups: Experiment 2.



Note: Same letter indicates no significant differences

ference was found between the simulation versions on subjects' game scores, $F(2,46) = 10.1$, $p < .001$, $MS_{error} = 113288.42$. Similar to Experiment 1, follow-up multiple comparisons on the means using Fisher's LSD method showed that subjects scored best on the game when given graphical feedback (mean = 728.2 seconds) as compared to those given textual feedback (mean = 1271.8 seconds) or graphical plus textual feedback (mean = 1007 seconds). Also, subjects given graphical plus textual feedback scored significantly better on the game activity than subjects given only textual feedback.

Interactivity. Means of the subjects' level of interactivity for each simulation version are graphed in Figure 5. A significant difference was found between the simulation versions on subjects' level of interactivity within the simulation, $F(2,46) = 14.0$, $p < .0001$, $MSerror = 136051.44$. Follow-up multiple comparisons on the means using Fisher's LSD method showed that subjects' patterns of interactivity matched those of their game scores: Interactivity in the simulation was lower with graphical feedback (mean = 517.1 mouse clicks) than with graphical plus textual feedback (mean = 815.8 mouse clicks), which, in turn, was lower than with textual feedback (mean = 1214.6 mouse clicks).

Frustration. In contrast to Experiment 1, significant differences were found between the three simulation versions on frustration, $F(2,46) = 4.7$, $p < .05$, $MS_{error} = 1964.82$. Subjects given textual feedback reported greater levels of frustration (mean = 134.3) than subjects given graphical feedback (mean = 88.3) or graphical plus textual feedback (mean = 98.9) (means are graphed in Figure 5). There were no significant differences in frustration between subjects given graphical feedback or graphical plus textual feedback.

GENERAL DISCUSSION

The purpose of this study was to explore how users interact and learn from a simulation when given different representations of feedback. In two experiments, subjects were randomly assigned to simulation versions that provided graphical feedback, textual feedback, or graphical plus textual feedback. A variety of issues and measures was studied in this research, such as patterns of interactivity, frustration, and of course, learning.

Experiment 1 provided subjects with only limited opportunity to interact with the simulation (i.e., 10 trials). Thus, inadequate exposure to the simulation is an obvious criticism. Experiment 2 was designed to resolve this problem by doubling subjects' exposure to the simulation (to 20 trials). In both experiments, subjects generally increased their scores from the pretest to the posttest (albeit quite modestly), however none of the three feedback conditions had a differentiated effect on subjects' explicit learning of the relationship between acceleration and velocity as indicated by the traditional performance measure used in this study. However, when subjects in both experiments interacted with the simulation containing only graphical feedback, they were much more successful at the game than when the simulation provided only textual feedback. Since success at the game also depended on correctly applying the relationship between acceleration and velocity, the game score provides an interesting alternative assessment to the learning of these principles. It is believed that the game score measured subjects' tacit knowledge of these principles, whereas the pretest/posttest measured subjects' explicit knowledge. Furthermore, in Experiment 2 the presence of textual feedback clearly created a disadvantage in being successful at the game, as indicated by the difference in game scores between subjects given graphical feedback and subjects given graphical plus textual feedback. The addition of textual feedback was probably distractive to subjects.

From a dual coding perspective, the simulation/gaming activity studied in this research effectively promoted representational and associative processing for the visual system, but not for the verbal system. Graphical feedback aided learning, but only at a tacit or experiential level. However, the graphical feedback did not promote referential processing *between* the visual and verbal systems: this feedback was not sufficient for subsequent reflection of the scientific principles underlying the simulation. Success at the pretest/posttest required an explicit understanding of these principles predominately in verbal form. Subjects were not able to make the transformation from visual/tacit to verbal/explicit. Designers of interactive learning environments are cautioned to match appropriately the feedback representation to the task, but not to assume that explicit understanding will automatically follow even if there is strong evidence to show that users are successful at completing the task. The challenge to designers is considerable—the learning environment must establish an effective partnership between the visual and verbal systems without overwhelming or distracting the user with multiple representations.

In considering the role of technology in learning, Norman (1993) makes an important distinction between two kinds of cognition: experiential and reflective. Experiential cognition is "a state in which we perceive and react to the events around us, efficiently and effortlessly" (Norman, 1993, p. 16). Reflective cognition, on the other hand, requires deliberate thought and reasoning over time. It also requires considerable effort, similar to what Salomon and Globerson (1987) call *mindfulness*. Of course, these two forms of cognition are not mutually exclusive—we rely on both everyday. Tacit understanding can be viewed as one outcome of experience, whereas explicit understanding is one outcome of reflection. At issue is how technology might provide or block opportunities for both kinds of cognition. Gaming environments, such as the one studied in this research, may be very good at providing important experiences in a domain, but it should not be assumed that these experiences will necessarily lead to explicit understanding. This is not a criticism of experiential learning, only an affirmation that experience is not a substitute for deliberate thought and reflection.

It is also very important to recognize that the issue of feedback representation is necessarily task specific. An important conclusion of this research is that different representations lead to different outcomes for specific tasks. This research does *not* propose that visual representations are better than verbal. It is also important to remember that the issue is not choosing one representation over all others, but to consider how different representations used separately or together contribute to different learning outcomes. For example, qualitative data collected in a separate, follow-up study suggest ways that learners may use different representations in productive ways (Rieber et al., in press): Subjects who were interviewed as they interacted with a similar simulation indicated that the textual feedback became important and meaningful only after they had an opportunity to build some working hypotheses about the underlying principles based on their interaction with the graphical feedback.

Beyond the cognitive evidence suggested in this study, subjects in Experiment 2 also became significantly more frustrated as they interacted with the simulation when provided with textual feedback rather than graphical feedback. For the simulated domain studied here, graphical feedback appeared to subjects to be more consistent with the demands of the task. A graphical interface seems like such a natural way to provide feedback in a simulation dealing with a physical science domain. Textual feedback places greater burdens on the user at the start and this added work can easily translate early on into frustration. Of course, the fact that one's initial strategies in completing a simulation or game may be more consistent with a graphical interface does not mean that there are not other learning strategies that may be better supported by textual feedback. Again, some of our other qualitative research shows that many subjects, though not all, begin to invent strategies that rely more on textual feedback than graphical feedback (e.g., Rieber et al., in press). One would expect that frustration would dissipate as people find and use other strategies that are consistent with the feedback representation provided by a simulation.

Another interesting finding in this study relates to the subjects' patterns of interactivity. Clearly, more interactivity with the simulation did not help in playing the game or answering the posttest questions. Subjects interacted less when the simulation provided graphical rather than textual feedback, though their games scores were significantly better when graphical feedback was provided. This serves as a reminder that feedback serves a qualitative role in simulations and that more interactivity is not necessarily better. Relating overt interactivity to game performance also raises the issue of task efficiency. The way certain tasks are represented in a simulation will certainly lead to different paths for completing the task successfully. In this study, the graphical feedback allowed users to complete the game in the fewest number of mouse clicks and in the shortest period of time. If the game task was the only desired learning outcome then clearly the graphical feedback would be preferred. Of course, subjects in this study were expected to go beyond the experiential knowledge gained solely through manipulating the surface representations to learn something about the science principles underlying the simulation. Obviously, much of formal school learning has similar expectations as well.

Several directions for future research are indicated. Future research should try to involve subjects in the activities for much longer periods of time, over a period of days or even weeks. Subjects may need to be engaged in the learning activity for extended periods of time before the transformation from tacit to explicit becomes possible. Research should also look for ways to embed instructional features that would help make the relationships in a simulation more explicit to users as they interact with it. For example, there may be ways to alter the simulation's interface to accomplish this, such as through the use of visual metaphors. Perhaps the most interesting topic of future research in this area concerns the use of gaming. One could argue that a game *is* a type of instructional overlay in that it provides a structure for helping the student to monitor goals, feedback, and outcomes. On the other hand, many students may focus so much on completing the game that they are distracted from reflecting on the underlying principles. Future researchers are also advised to consider a blending of quantitative and qualitative methods to best understand how students interpret different feedback representations in relation to learning strategies they develop over time.

In conclusion, representation matters. As Norman (1993) notes, ideal representations must do three things:

1. Appropriately show important, critical features of a domain while ignoring the irrelevant;
2. Be appropriate for the person; and
3. Be appropriate for the task.

Instructional designers and programmers face substantial challenges in optimizing these three demands in constructing innovative instructional simulations. This study provides initial evidence, at least, that these demands can be neither ignored nor assumed. Decisions on the representation of a simulation's feedback are likely to depend on a complex interrelationship between the domain being modeled in the simulation (e.g., physics, cooking, giving a speech, etc.), outcomes within that domain (e.g., memorizing, concept formation, problem solving, etc.), levels of understanding (e.g., tacit, explicit, shallow, deep, etc.), instructional support (e.g., discovery, guided, directed, etc.), and the user's learning style (e.g., visualizer, verbalizer, field dependent/independent, etc.). In short, "the form of representation most appropriate for an artifact depends upon the task to be performed" (Norman, 1993, p. 75). Although computers afford the design of highly interactive learning environments, many challenges to *effective* design remain. □

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