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Animation, Incidental Learning, and Continuing Motivation

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The effects of animated presentations on incidental learning and the degree to which various computer practice activities contain intrinsically motivating characteristics as measured by continuing motivation were studied. A total of 70 4th graders participated in an introductory lesson on Newton's laws of motion. Between-subjects factors consisted of visual presentation (static graphic vs. animated graphic) and practice order (questions/simulation vs. simulation/questions). Within-subjects factors consisted of learning intent (intentional vs. incidental) and test interval (immediate vs. delayed). Results showed that students successfully extracted incidental information from animated graphics without risk to intentional learning but were also more prone to developing a scientific misconception. In addition, when placed in a free-choice situation, students overwhelmingly chose to return to the practice activity consisting of the computer simulation.

Recent advances in authoring computer-based instruction (CBI) have provided designers with relatively easy means of adding diverse and elaborative features to instructional software. Features that once demanded advanced programming skills and liberal development time lines can now be almost casually incorporated. Animation has long been a popular feature in CBI, and its use, along with the use of other types of graphics, is often encouraged (Bork, 1981; Caldwell, 1980). Unfortunately, animation is frequently added to CBI without serious concern for its true instructional purpose or impact.

Instructional research has focused on two fundamental applications of animation in CBI: animation as a presentation strategy and practice activities involving interactive animated graphics such as those found in visually based simulations (see Rieber, 1990a, for a review). Recent reports have offered encouraging results for both applications. Although animation can be a very dramatic visual effect, the efficacy of animated presentations on cognition is quite subtle. Research indicates that differentiated learning effects due to externally provided animated visuals, as compared with learning effects provided by static visuals, are particularly dependent on task requirements, cognitive load, and attention-gaining devices (Reed, 1985; Rieber, 1990b; Rieber, Boyce, & Assad, 1990; White, 1984). The research pool is not large, however, and many of the studies that have been conducted have unfortunately been prone to confounding and poor designs, such as the failure to control for static versus animated visuals in the treatment conditions.

An interesting study that demonstrates the elusive nature of animation effects was conducted by Reed (1985). The study involved a series of four iterative experiments (the results of each experiment being used to improve the design of the next) to test the teaching of algebra word problems with computer animation. The animated displays aided learning only when the graphic presentations were paired with an externally provided lesson strategy that required students to make estimations. The additional activity appeared to help students to attend to the features in the animated display that were most informative and helpful for solving the word problems on the posttest.

Congruency between a learning task and lesson presentation has been a longstanding ground rule for predicting picture facilitation effects (Levin, Anglin, & Carney, 1987; Levin & Lesgold, 1978). One would expect that animation, like any graphic or picture, would facilitate learning tasks that require or could benefit from external visualization. However, animation additionally brings the attributes of motion and trajectory to a given learning situation (*trajectory* is defined as the direction of travel of a moving object). For example, animation should aid learning if the learning task requires the visualization of a concept or rule over time (e.g., "all plants grow") or in a certain direction (e.g., "Lewis and Clark charted the wilderness as they traveled westward"), or a combination thereof (e.g., physical principles such as acceleration and velocity); otherwise, no differentiated effects of animated visuals, as compared with static visuals, would be expected. Animation would also be expected to help students to visualize a dynamic process that is difficult or impossible for them to visualize on their own, such as the sequence of an operating internal combustion engine. Even if the visualization of motion and trajectory are important cognitive skills for a given learning task and are externally provided in a lesson display through animation, learners must still be able to attend to the salient features of the display. The mental processes of selection and organization are particularly important considerations in designing animated displays because of the temporal nature of these displays; students may not have a second chance to view the animation once a sequence is completed. Even if students attend to an animated display, they often fail to notice the information it contains. For example, differences in motion or trajectory that an expert may see as obvious

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may be totally overlooked by a novice (Rieber, 1990b; White, 1984).

Perceptually animation is an example of apparent motion, which is the phenomenon of perceiving motion when there is, in fact, no physical movement of an object in the visual field (Ramachandran & Anstis, 1986). When an animated sequence is carefully produced, a person "sees" motion in a collection of separate and static visual displays (at least 15 frames per sec is usually the minimal requirement) through a top-down mental process called *correspondence* (Mack, Klein, Hill, & Palumbo, 1989). Because animation can be thought of as the external visualization of an idea over time in a certain direction, general theoretical support of animated visuals is believed to be provided by one of several theories of knowledge representation that support the use of visuals (pictures or other types) as an aid for memory or learning tasks. Although competing hypotheses exist, considerable empirical support is given to the dual-coding hypothesis advocated primarily by Paivio (1986; see review by Anderson, 1978). Dual-coding theory suggests that long-term memory consists of two separate but interdependent coding mechanisms: one verbal (or semantic) and the other visual. Dual-coding theory consists of two important assumptions (Kobayashi, 1986). The first is that the two separate codes have additive effects so that if information is dually coded it is more likely to be remembered. With regard to memory tasks, two codes are better than one. The second assumption is that the availability of the two codes is different for verbal and visual information such that pictures are more likely to be dually coded than are words. These two assumptions help explain research findings that show that pictures are often better than words for memory tasks. When information is dually coded, the probability of retrieval is increased because if one memory trace is lost, another is still available. Retention can be enhanced by external pictures if they promote the activation of dual coding. In this article I argue that extensions of dual coding can help explain and predict learning effects produced by animated displays (Rieber & Kini, 1990). As dual coding would suggest, the motion and trajectory of an image can be represented by verbal or propositional codes. These codes can be represented visually by animation or video and verbally by temporal or spatial relations to an argument, such as "fast," "slow," "up," or "down." Visual and verbal redundancy of motion, trajectory attributes, or both should facilitate learning, again assuming that these attributes are necessary for the learning of certain facts, concepts, or principles.

Research has indicated that the way in which a problem is represented is important in determining if and how the problem is solved (Eylon & Linn, 1988). Representations of the problem context would be expected to be helpful only if students recognize the most salient features of the representation and consequently understand how those features relate to the problem. Eylon and Linn (1988) noted that "novice students are weak in discriminating the central features of representation and may, therefore, be misled into emphasizing incorrect features" (p. 277). Hence, the distinction among information that is explicit, information that is implicit, and information that is absent in an external visual representation may vary depending on the point of view of the designer or student and also may depend on the position the student occupies on the novice-to-expert continuum. A designer would be expected to make information in a visual representation that directly relates to the learning goal as explicit as possible. However, it is also possible to represent information implicitly in a visual representation that is secondary or incidental to the learning goal. For example, in addition to gains in intentional learning, I (Rieber, 1990b) reported initial evidence of animation's role in contributing to incidental learning. Elementary school students demonstrated modest success in attending to incidental information contained in a single animated display. A goal of the present study was to validate this preliminary finding and to investigate its implications further.

The study of incidental learning is well established (Ackerman, 1985; Goldberg, 1974; Klauer, 1984; Lane, 1980; Sagaria & Di Vesta, 1978). Past research has primarily focused on interactions between text-processing activities, such as prequestions and postquestions, and intentional and incidental learning. The search for true "mathemagenic" activities, that is activities that give "birth" to learning (Rothkopf, 1966), has led researchers to understand that most instructional activities incur trade-offs between intentional and incidental learning in which contributions to one generally impede the other. Most of this research has concentrated on learning from prose, although several imagery studies have been reported that indicate that recall of incidental information is more robust for pictures than for words (Ghatala & Levin, 1981). Negative consequences of incidental learning from animated displays, such as interference with intentional learning, are anticipated and must be documented.

Traditional CBI design, based on systems approaches (see Reigeluth, 1983, for a review), has been concerned only with intentional learning, that is, the extent to which predetermined learning objectives are mastered. Unfortunately, this approach can also lead to instructional designs that are unnecessarily self-limiting and restricting and that are apt to assign a passive role to the learner. The ability of the learner to elaborate upon instruction, as well as to induce rules and principles that are not intentionally taught, is usually overlooked or ignored. The first objective of this study was to investigate whether students would be able to attend to incidental information contained in animated visuals and subsequently induce a physical science principle from this information without sacrificing intentional learning.

Previous research has demonstrated that animated presentations interact with the practice activities provided in CBI. In traditional CBI, questioning strategies have been used as successful practice activities (e.g., Hannafin, Phillips, & Tripp, 1986). I and my colleagues (Rieber, 1990b; Rieber et al., 1990) compared the effects of questioning strategies with structured simulations as practice activities in science instruction. Adults performed equally well with both forms of practice, whereas elementary school children performed best when given the experiences with the structured simulation. The structured simulations, which were based on the work of diSessa (1982) and White (1984), consisted of animated graphics that obeyed the laws of motion and were under student control. Brown (1983) termed these applications of animated graphics "interactive dynamics." The graphics change continuously over time depending on student input, thus acting as a form of instantaneous visual feedback (Reed, 1985). I speculate that the success of the structured simulations with children was due in part to the apparent intrinsic motivational appeal of the simulation; students were encouraged to fantasize about being the pilot of a starship in outer space.

Intrinsic motivation is defined as the motivational value of the content itself without the provision of external incentives to induce participation. Intrinsically motivating instruction relies on student-driven incentives, rather than on external lesson reinforcement (Malone, 1981). In fact, the addition of extrinsic incentives, such as grades and other rewards, can often undermine or destroy the intrinsic appeal of many activities for students, particularly in young children (Condry, 1977; Greene & Lepper, 1974; Lepper, Greene, & Nisbett, 1973). Lepper (1985) raised two main issues related to research on intrinsic motivation. The first issue concerns describing the determinants of intrinsic motivation, and the second concerns the way in which these determinants relate to instructional effectiveness. Tasks or activities that are intrinsically motivating possess several commonalities. Malone (1981) proposed a framework on which to define what makes certain activities intrinsically motivating, which is based on challenge, curiosity, and fantasy. Malone's discussion is particularly relevant to this study because he specifically applied this framework to the design of computer games. Challenge in an activity can usually be induced by establishing goals that have uncertain outcomes. The goal should be personally meaningful to the learner such that the skills or knowledge being learned are viewed as important because they help the learner to achieve the goals. Tasks need to be designed to be optimally challenging, such that they are not too easy or too difficult. Yet, perhaps most importantly, the tasks should elicit feelings of competence, or self-efficacy, in solving problems that students perceive as relevant and important. This enhances one's self-concept and leads to a feeling of control over one's own success (Weiner, 1979).

Closely related to challenge is curiosity. A person's curiosity is usually piqued when an activity is viewed as novel or moderately complex. In addition, curiosity is usually increased by activities that offer a certain level of surprise. This occurs when the expected and actual outcome of an activity are different or incongruent, a phenomenon that Berlyne (1965) termed "conceptual conflict." Again, however, both challenge and curiosity (produced by a conceptual conflict) must be optimally maintained to be effective. A task that is perceived as too easy quickly loses appeal, and a task that is seen as too demanding is avoided. Likewise, a conceptual conflict between expected and actual task outcomes can encourage a learner to seek to resolve the conflict but can quickly lead to frustration if the conflict is too confusing or bewildering. Norman (1978) termed optimal levels of conceptual conflict "critical confusion."

The use of fantasy in learning entails providing learners with a meaningful context for learning that is easy to augment with their imaginations. The context is meaningful to the learner in the sense that it offers a very personal degree of fascination and intrigue, which is easily transferred to play activities. Fantasy educes mental images of a context in which a learner is not actually present. The use of fantasy is common in theme parks and children's films and television programs. Malone (1981) termed instruction that incorporates fantasies in this way "intrinsic fantasies" because the skills to be learned are integral with the fantasy, such as learning about latitude and longitude to locate a "pirate's sunken treasure."

These characteristics of intrinsic motivation are all similar to Keller's (1983) synthesis of affective attributes that form the basis of his Attention, Relevancy, Confidence, and Satisfaction (ARCS) model of motivational instructional design. The degree to which these determinants are present in instruction and the ways in which they relate to differences in learning are not clear. Some examples of differences in learning in the context of instruction that does or does not provide intrinsic incentives are (a) the intensity of a learner's arousal and attention to a task, (b) the depth of involvement, and (c) task persistence (Lepper, 1985). Each of these in turn would influence the amount of time learners actually spend on task and also the level at which mental processing occurs (Maehr, 1976; Malone, 1981; Rotter, 1954).

Therefore, the second objective of this study was to investigate the underlying motivational characteristics of the structured computer simulations, which were found to influence the learning of science principles in my previous study (Rieber, 1990b). This objective is a preliminary attempt at validating whether a specific computer-based instructional context holds intrinsically motivating characteristics for children. Measures of continuing motivation, such as choosing to return to an instructional task in a free-choice situation, have been used successfully to estimate the construct of intrinsic motivation (e.g., Kinzie & Sullivan, 1989). Continuing motivation can be defined as an individual's willingness to return to an activity once external pressure to do so has ceased (Maehr, 1976).

In summary, there were two purposes of this study, each pertaining to a separate research question. Both were incorporated into the present research design on the basis of the philosophy that instructional strategies interact, a perspective that is supported by findings from previous research with these materials in children (Rieber, 1990b) and in adults (Rieber et al., 1990). The first purpose was to investigate the effects of computer-animated presentations on incidental learning. It was not my intention to study the effects of animated presentations on intentional learning, as this was studied previously (Rieber, 1990b): Children's rule learning was found to increase with the addition of animated presentations. I examine intentional learning in the present study only as it relates to incidental learning, that is, the degree to which one type of learning is interfered with or impeded by the other. I hypothesized that animated presentations would promote incidental learning without significant loss to intentional learning. The second purpose of this study was to investigate the locus of motivation to participate in computer-based practice activities. I hypothesized that students would choose to return to practice activities involving interactive dynamics more often than other computer practice activities or even other high-interest, nonlesson activities, such as paper puzzles. I contend that free-choice preferences constitute a valid, though perhaps indirect (but more direct than introspection data, for example), measure of the degree of intrinsic motivation contained in each of the various activities. I only suggest that these data provide an initial and preliminary indication of which motivational characteristics underlie certain computer-based simulations.

Method

Subjects

The subjects consisted of 70 fourth-grade students from an urban public elementary school. Participation, though voluntary and based on parental consent, was unanimous in the cooperating classrooms. A total of 36 boys and 34 girls participated.The average age was 9.8 years ($SD = 0.56$).

Lesson Content

The CBI lesson, first developed for previous studies (Rieber, 1989, 1990b; Rieber & Hannafin, 1988) but modified for this study, described and explained several aspects of Newton's laws of motion. The lesson was divided into two parts. Part 1 introduced students to Isaac Newton and his first law of motion, which states that an object in motion remains in motion and that an object at rest remains at rest. Part 2 provided applications of Newton's first law and specific applications of Newton's second law (i.e., motion of an object resulting from varying the forces that act on it), which is summarized by the equation that force equals mass multiplied by acceleration ($F = ma$). All information was presented at an introductory level in the context of one-dimensional motion without friction or gravity (the students were asked to imagine the events of the lesson as taking place in outer space).

Lesson Versions

Two levels of visual presentation (static graphic vs. animated graphic) were crossed with two levels of practice order (questions/simulation vs. simulation/questions). The former factor relates to the research question dealing with effects of animated displays on incidental learning, and the latter factor relates to the research question of intrinsic motivation contained within structured simulation activities on the computer.

Visual presentation. In each visual-presentation condition, the lesson narrative was supplemented with either static or animated graphics. In the static-graphics condition, forces were represented by a foot giving an object a kick, such as a ball or a concrete block. Motion and trajectory attributes were represented by arrows and path lines. The animated-graphics condition also involved the ball, block, and foot symbols. However, the object was then animated to show the motion and trajectory resulting from the force applied to it. Both the static and animated visuals elaborated the textual information.

In addition to the information that was intentionally taught in both the static-graphic and animated-graphic conditions, another application of Newton's second law—that dealing with the motion that results when the mass of an object varies—was incidentally demonstrated in the animated-graphics condition. This law predicts that when two objects of different masses are both acted on by the same size force, the acceleration experienced by the object with larger mass is less. The computer animated a large "concrete block" moving very slowly across the computer screen after being kicked with the same size force that had just been applied to a small animated "soccer ball," the images of which are similar to those illustrated in Figure 1. The incidental information contained in the animation attributes was in the form of different speeds of the two moving objects of different masses on the computer screen. No attempt was made to teach or explain why the block moved more slowly than the ball. By design, no incidental information was contained in the static visuals as no information related to speed was contained in the arrows or path lines.

One reviewer was concerned that the incidental-learning variable was biased in favor of the animated condition because the faster moving object was both lighter and round and because round objects moving faster than rectangular ones is compatible with the students' prior knowledge. The choice of objects used in this study was based totally in favor of a meaningful context in which fourth-grade students would clearly be able to distinguish the concept of mass solely on the basis of the context provided, the idea being that students would consider the soccer balls as being intuitively "lighter" than the concrete blocks. In order for the incidental-learning variable to have any validity, it was essential that students unambiguously deduce the concept of mass from the two objects provided. Soccer balls and concrete blocks were chosen as prototypical examples of the two ends of the mass continuum that could be meaningfully manipulated for the children of this age. So, whereas it is possible that the inconsistency in shape may be a source of confounding, one could also argue that the students were far more likely to attend to the meaning provided by the context than merely to the meaning provided by the shape features of the objects. Of course, it may have been possible to use other prototypical objects of different masses without manipulating shape, and this issue should be considered in the design of follow-up studies.

Practice order. Each level of practice order consisted of giving all students two types of practice activities but in different order. The first practice activity consisted of multiple-choice questions. The questions covered the relevant material in the respective lesson part. Feedback was provided to the students in the form of knowledge of correct results. The second practice activity involved the student in a structured simulation. In the lesson students were given increasing levels of control over a simulated, free-floating object called a starship. This structured simulation, an application of the "dynaturtle microworld" developed by diSessa (1982) and White (1984), had been

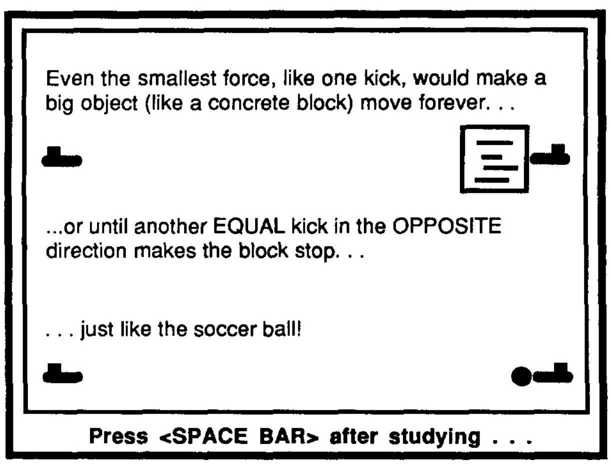

Figure 1. Example of a computer screen that used animation to present intentional and incidental information. (The "concrete block" and the "ball" were each kicked once. The animation depicted the ball's speed as dramatically greater than that of the block.)

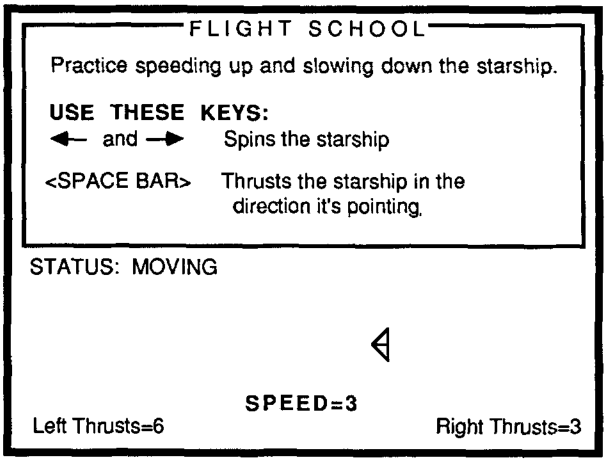

Figure 2. Snapshot of the computer screen during the structured simulation activity. (From "Using Computer Animated Graphics in Science Instruction With Children" by L. P. Rieber, 1990b, *Journal of Educational Psychology, 82,* p. 136. Copyright 1990 by the American Psychological Association.)

shown to positively affect lesson performance in prior research with children of this age (Rieber, 1990b). An example of this activity is illustrated in Figure 2. Students participated in the practice activities in the respective order (questions/simulation or simulation/questions) after each of the two lesson parts. It was important that all students have equal opportunities to experience both forms of practice so that interpretation of the free-choice data would be valid. However, I anticipated that the first activity might orient students to the second activity, thus resulting in different success patterns for each activity. This could affect the motivating appeal for each activity. Therefore, I added practice order to the experimental design to prevent the order of activities from confounding the study. It was not my intention to study the performance effects of each practice activity in this experiment, as the efficacy of these activities has been demonstrated elsewhere (e.g., Rieber, 1990b; White, 1984). For example, in my previous study (Rieber, 1990b), children in the structured simulation condition outperformed those in a no-practice control condition, whereas children in the other practice condition (questions) did not.

Dependent Measures

Posttest. The 24-item posttest measured two types of rule learning: intentional and incidental. Intentional learning is defined as learning those objectives that were directly taught in the lesson through the combination of verbal (text) and visual means. The intentional-learning outcomes were applications of Newton's first law and a specific application of Newton's second law, which holds that the initial acceleration and subsequent velocity of an object is proportionally related to forces that act upon it in one-dimensional space. For the purpose of the intentional learning goals, Newton's second law itself (i.e., $F = ma$) was not taught. Students were taught only the application of the law that predicts that the larger is the force exerted on an object, the larger the initial acceleration and resulting velocity of the object will be and that equal forces in opposite directions cancel each other out.

Incidental learning is defined as learning those objectives that are not directly taught but only implied through contextual cues provided in several of the animated visual displays. The incidental-learning outcome was another application of Newton's second law, which predicts that the initial acceleration of an object produced by any given force decreases as the mass of the object increases. An example of this is the following: Force A is applied to Object B and Object C; if Object C has twice the mass of Object B, then the initial acceleration and the resulting velocity of Object C is half that of Object B.

The posttest was administered twice: first, in two parts immediately upon completion of the relevant lesson parts, and then again approximately 2 days later in full as a measure of learning decay/durability. Half of the intentional and incidental questions were presented in an all-verbal form and half contained accompanying visuals. Because question type and question content were not controlled however, direct comparisons of the two question types are not warranted. Two examples of actual test questions are provided in Figure 3.

Two questions were added to the final administration of the posttest that tested a simple application of Newton's law of gravitation. This object was not taught in any form during the lesson. However, I anticipated that the animated visuals might promote the misconception that two objects of different masses would fall at different speeds when dropped to the earth. These two questions

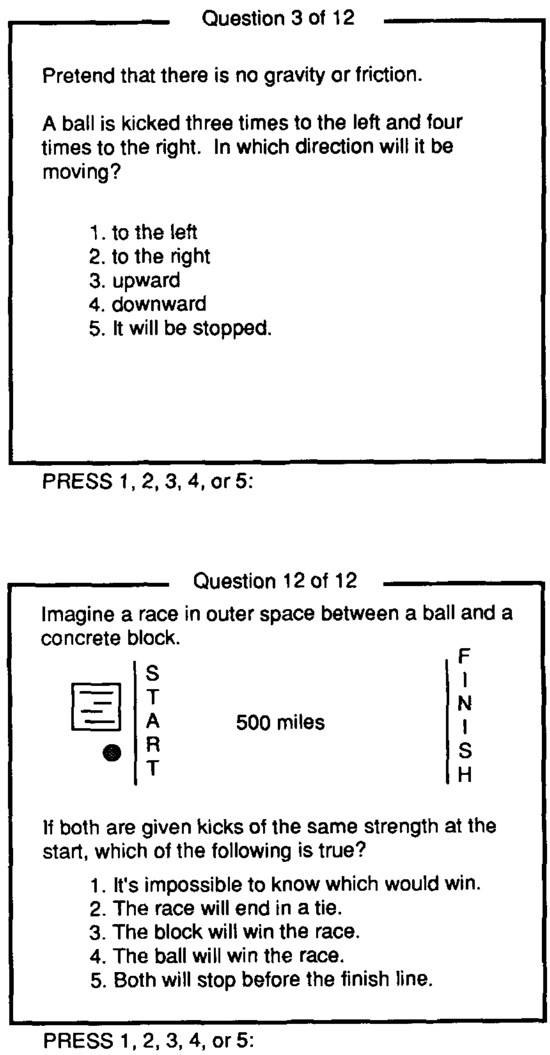

Figure 3. Representative examples of the posttest questions. (The question above measures intentional learning and the question below measures incidental learning.)

provided a preliminary measurement of whether such a misconception was actually formed by students.

K-R 20 reliability of all 50 questions was .93. Respective reliability coefficients and number of questions for each of the subscales were as follows: .87, 24 (immediate); .87, 24 (delayed); .91, 28 (intentional); .95, 20 (incidental); .64, 2 (law of gravitation).

Response latency. Cognitive perspectives on learning, such as those based on information-processing models, anticipate other sources of variance in learning besides performance. For example, these models predict variations in the time necessary to consider problems and formulate answers (Gagné, 1985). Performance data often do not adequately reveal learning characteristics such as strength of encoding and fluency of retrieval. Whereas the use of latency as the only source of information about cognitive processing is prone to criticism (Siegler, 1989), analyses based on the combination of performance and latency data often provide a more complete understanding of learning than does either data source alone. For these reasons the time required by students to process each of the posttest questions was recorded. Processing time is measured as the time (in seconds) taken by students to press the appropriate key once prompted to do so. This variable provides an important indirect measure of the organization strength of initial encoding as evidenced by retrieval time.

Continuing motivation. Immediately after completing the second administration of the posttest on the 4th day, students were given three choices: (a) answer more practice question just for fun, (b) spend more time in the structured simulation, or (c) complete a word-find puzzle on another topic. Students were told that they could switch between activities if they wished to do so. Continuing motivation of the practice activities was measured by first-choice frequencies of the first two options as compared with the first-choice frequency of the puzzle activity.

Procedure

All instruction and testing was administered by computer over the span of four, 30-min computer sessions. The first session acted as a general orientation to familiarize students with the materials and nature of the project. The second session presented Lesson Part 1, followed by practice and then 12 posttest questions relevant to that part. The third session presented Lesson Part 2, followed by practice and then 12 posttest questions relevant to Part 2. At the close of each of the first three sessions, word-find puzzles of unrelated topics were distributed to all of the students as a reward for "all their hard work that day." Each puzzle contained 20 words embedded vertically, horizontally, or diagonally in a matrix of random letters consisting of 32 rows and columns. All students were very familiar with the design of the puzzles and eagerly accepted and worked on them until it was time to return to their respective classes. They were permitted to take the puzzles with them at the conclusion of each session. The fourth session involved a readministration of the original 24 posttest questions and 2 additional questions that measured Newton's law of gravitation. As previously indicated, these 2 questions were added as a preliminary measure of whether the animated graphics promoted misconceptions. After the posttest, students were given the choice to work on either of the two computer-based practice activities (questions or simulation) or an irrelevant, though highly motivating activity, which again consisted of a word-find puzzle of the same design but of a different topic as those distributed after the previous sessions. Each of the four sessions lasted approximately 30 min, amounting to about 120 min of learner time over the course of about 10 days. Students were randomly assigned to one of the treatment groups as they arrived at the computer lab for the first session. Once instructed to begin at the start of each session, students completed the lesson individually.

Design

In this study a $2 \times 2 \times (2 \times 2)$ factorial design was used with two between-subjects factors (visual presentation vs. practice order) and two within-subjects factors (learning intent vs. test time).[1] The between-subjects factors consisted of two levels of visual presentation (static graphic vs. animated graphic) and two levels of practice order (questions/simulation vs. simulation/questions). The within-subjects factors consisted of two levels of learning intent (intentional vs. incidental) and two levels of test time (immediate vs. delayed). A mixed-factor analysis of variance (ANOVA) was used to analyze the quantitative data. This analysis is commonly known as a repeated ANOVA (Winer, 1971). The within-subjects factors also served as dependent measures. Because cell sizes were unequal, data were analyzed with the least squares Type III sum of squares method within the framework of the general linear model (GLM). A chi-square analysis was used to test students' first-choice preferences of each postlesson activity as a measure of continuing motivation of the practice questions and the simulation.

In addition, separate analyses were conducted on the questions measuring misconceptions of Newton's law of gravitation and the response latency data from the posttest.

Results

Posttest

Percent means and standard deviations of student posttest scores are presented in Table 1. A significant main effect was found for visual presentation, $F(1, 66) = 60.89, p < .001, MS_e = 1{,}322.35$. However, interpretation of this effect must be qualified because of its interaction with learning intent, $F(1, 66) = 19.83, p < .0001, MS_e = 1{,}042.84$. Figure 4 illustrates the nature of this ordinal interaction. There was a larger difference between animated-graphics and static-graphics subjects on the incidental-learning questions (67.5% vs. 16.3%) than there was on the intentional-learning questions (74.2% vs. 57.4%). As expected, students in the static-graphics condition performed at about the guessing level on incidental questions. This result supports the first hypothesis of this study that students receiving animated demonstrations of

[1] The research design originally contained an additional within-subjects factor, called Visual Testing Format, which controlled for the use of visuals in each question (i.e., all verbal information or a mixture of verbal and visual information), for the purpose of studying how accompanying visuals may influence student responses on test questions. However, the inadvertent confounding of question type and question content, as noted by a reviewer, precluded the usefulness of any information gained by this factor. Hence, the research design and analyses were revised (and simplified) by collapsing across the Visual Testing Format factor, and this is the analysis reported here. Among the remaining factors, only one change was noted in the results from the original to the revised analyses. In the revised analysis, a three-way interaction was found between Learning Intent, Test Time, and Visual Presentation, $F(1, 66) = 5.88, MS_e = 11.94, p < .025$, on the response latency measure. However, an a priori decision was made to disregard interactions involving three or more factors, and so this interaction was not interpreted. This interaction was not significant at $p < .05$ in the original analysis, which included the Visual Testing Format factor.

Table 1
Mean Percent Scores and Standard Deviations for the Posttest

Visual presentation	Practice order	*n*	Immediate test				Delayed test			
			Intentional		Incidental		Intentional		Incidental	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Animated graphic	Questions/simulation	17	71.4	25.9	69.4	28.4	78.6	20.7	70.0	28.7
	Simulation/questions	17	71.8	22.9	64.7	31.0	74.8	19.9	65.9	28.5
Static graphic	Questions/simulation	17	57.1	21.6	19.4	16.4	56.7	22.9	16.5	25.7
	Simulation/questions	19	58.6	31.2	17.4	22.1	57.1	32.7	12.1	23.5

incidental information would attend to, understand, and retrieve this information when tested even though no formal attempt was made to teach or explain the principle. Follow-up analyses indicated that the animated-graphics group performed significantly better than the static-graphics group on incidental-learning questions, $t(66) = 76.99$, $p < .0001$, and also on intentional-learning questions, $t(66) = 8.34$, $p < .01$, the latter of which is consistent with previous research (Rieber, 1990b).

Among the within-subjects factors, significant main effects were found for learning intent, $F(1, 66) = 38.15$, $p < .0001$, $MS_e = 1{,}042.84$. Not surprisingly, students scored higher on questions measuring intentional learning (M = 65.6%) than on questions measuring incidental learning (M = 41.4%). All other effects had associated Fs < 4.0, ps > 0.5.

Response Latency

A main effect was found for learning intent, $F(1, 66) = 121.22$, $p < .0001$, $MS_e = 17.91$. Students took significantly less time to answer questions measuring intentional learning than questions measuring incidental learning. However, an ordinal interaction was also detected between learning intent and visual presentation, $F\ (1, 66) = 7.90$, $p < .01$, $MS_e = 17.91$. There was a larger difference between the animated-graphics and static-graphics groups with regard to the time necessary to respond to incidental questions (19.5 sec vs. 17.2 sec) than there was on the intentional-learning questions (12.5 sec vs. 13.1 sec). Whereas reasons for this effect are open to speculation, one hypothesis based on an information-processing model of learning is offered. Students in the animated-graphics group were required to process the incidental information represented in the animated visuals for the first time during the posttest (i.e., the incidental information was brought to their conscious awareness for the first time on the posttest). If students encoded the incidental information as expected (and as the data listed above support), time would be necessary to retrieve this information and to formulate a rule that could be used to answer the question. Because students in the static-graphics group had no incidental information presented to them with which to answer the question, they had to revert to guessing or to personal experience. Latency rates for students in the static-graphics group for these questions would be expected to be lower than for students in the animated-graphics group if they were guessing at shallow levels of mental processing. Of course, a converse argument would hold that guessing can take a considerable amount of time when a guess is formulated at deeper levels of processing, such as in the case when partial information is available and there is a strong personal investment in the outcome.

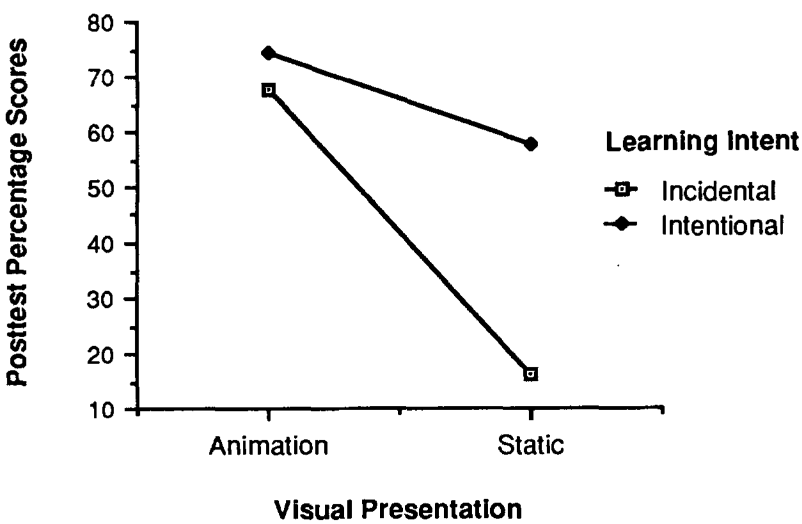

Figure 4. Interaction between visual presentation and learning intent.

A main effect was found for test time, $F(1, 66) = 50.97$, $p < .0001$, $MS_e = 19.56$. Students took significantly less time to answer the posttest questions during the second administration of the posttest. Retrieval time would be expected to decrease during retesting when questions are identical to those administered originally and especially when the retesting occurs within 48 hr, both of which were the case in this study. However, an ordinal interaction was found between test time and visual presentation, $F(1, 66) = 7.98$, $p < .01$, $MS_e = 19.56$. Students in the static-graphics group varied less in response time between the first and second administrations of the posttest (16.0 sec vs. 13.5 sec, respectively) than did students in the animated-graphics group (18.0 sec vs. 12.9 sec, respectively). This interaction is probably an artifact of the rate of guessing on incidental questions by the static-graphics group. Guessing would not be expected to produce much variance in latency rates from one test administration to the next. In contrast, the second encounter with the incidental-learning questions would require less processing time for students in the animated-graphics group than would their first encounter if students recalled their problem-solving strategy from the first encounter and used it during the second encounter.

Continuing Motivation

Respective first-choice frequencies for each of the three postlesson activities were as follows (the first number indicates the raw frequency, and the second number indicates percentage of total first choices): questions 3, 4.3%; simulation, 42, 60.0%; and puzzle, 25, 35.7%. For the purposes of a chi-square analysis, answering more practice questions served as a nonchoice and therefore was removed from the final analysis. Overall, students first chose to participate in the structured simulation more often than the puzzle activity, $\chi^2(1, N = 67) = 4.31$, $p < .05$. This result supports the second hypothesis of the study, which states that the practice provided by the structured starship practice held intrinsically motivating appeal for the students, assuming that participation in the puzzle activity (after three previous puzzles) remained a strong motivator for these students. I contend that this appeal would lead students to choose to stay on task longer in meaningful ways. This result further clarifies performance effects of this practice activity as reported by Rieber (1990b). Chi-square tests revealed no difference in first-choice postlesson activities as a function of either visual presentation or practice order, both $ps > .05$.

Student Conceptions of Gravitation

A significant main effect was found for visual presentation, $F(1, 66) = 18.24$, $p < .0001$, $MS_e = 1{,}044.19$. Students in the animated-graphics group ($M = 5.9\%$, $SD = 16.4$) performed significantly worse on the 2 questions measuring a simple application of Newton's law of gravitation than did students in the static-graphics group ($M = 38.9\%$, $SD = 41.6$). This suggests that students in the animated-graphics group were more prone than other students to the misconception that Newton's second law predicts the free-fall characteristics of objects of different masses on earth. This result provides an important counterbalance to the apparent ability of students to attend to animated visuals that incidentally demonstrate a scientific principle. Although students may be appropriately attending to the details in animated graphics displays, they may be drawing a series of conclusions, some of which are appropriate and some of which are not. This phenomenon is consistent with previous research on misconceptions in science in which people formulate conceptions of physical phenomena on the basis of daily observable events (see Eylon & Linn, 1988, for a review). Without direct guidance, such as that provided by explicit instruction, students may formulate potentially erroneous "theories" about the physical world.

Discussion

The first purpose of this study was to investigate the ability of students to attend to incidental information contained in an animated visual and to then extract and induce science principles. The animated-graphics group was given demonstrations of an application of Newton's second law in which the masses of two objects varied, but the forces acting on them remained constant. However, the fact that these demonstrations represented a distinct extension of this principle was never brought to their attention. In fact, the demonstrations were presented in the context of explaining other lesson content. The only overt learning goals—those goals of which the students were made consciously aware—were goals related to the intentional-learning outcomes. I believe that attention to intentional learning alone placed significant cognitive loads on students. Yet, the students were able to gain an initial understanding of the incidental information without any apparent sacrifice to intentional learning. The results reported in this article demonstrate the rather startling ability of fourth-grade students to attend to, to formulate, and to use a sophisticated science principle introduced in an incidental fashion, albeit this application occurred strictly on near-transfer tasks. All of the incidental information was represented by the relative motion of screen objects. An animated concrete block moved dramatically slower than an animated soccer ball after forces of equal sizes were applied to each.

Larkin and Simon (1987) identified three cognitive processes in which learners engage when using an external representation to solve a problem: search, recognition, and inference. Although Larkin and Simon's research compared the computational efficiency (in mental terms) between propositional representations and diagrams, their model provides useful insights into the questions asked in this article as well. When solving problems, learners must apply an effective attention-management plan to be able to effectively search a given representation for certain information needed at a certain time. A successful search leads a learner to recognize matches between information in the representation, with needs or gaps suggested by one or more production systems directing the search. Once the desired information is recognized, the learner must then infer (organize and integrate) this new information with any previous information in memory. The type of external representation (such as verbal or visual) and the nature of each that is provided can have different effects on each of these processes. Spatial representations, such as diagrams, offer significant advantages for the search and recognition processes when solving problems in content areas in which information is naturally organized in spatial ways, such as geometry and physics. In these cases, diagrams usually reduce the computational burden of memory to perform the search and recognition processes. Furthermore, more informational relationships are made explicit in visual representations than in propositional representations. The increased number of such relationships can also aid search and recognition. In this study, I investigated the ability of students to recognize the implicit information related to Newton's second law in the animated presentations. Students were able to recognize and infer this implicit information correctly, presumably because the implicit, or incidental, information was easily accessed and recognizable in the animated presentations through the relative motion of the objects. I suggest that the implicit, or incidental, information in the animated display placed little additional cognitive load on the students.

However, this result is tempered by the large number of students who continued to apply this incidental information to other, inappropriate contexts. Students in the animated-graphics condition were much more likely to hold misconceptions about the effects of gravity on objects of different masses than were students in the static-graphics condition. This is not really surprising. The animated demonstrations of Newton's second law occurred in a simulated gravity-free/frictionless environment. The concept and effect of gravity was purposely removed from the discussion. Without additional guidance, it is logical and intuitive to apply Newton's second law to contexts in which objects of different masses are freely falling on earth (such an intuitive assumption led Galileo to demonstrate otherwise—or so the legend goes—at the leaning Tower of Pisa). I suggest that in this case the animated displays actually primed students to fall into the misconception trap. Students appeared to attend to the surface-level features of the animated displays, such as the relationship between mass and movement. Given no other information or guidance, they made a legitimate, though incorrect, extension of the principle to the context of gravitation. They appeared to draw upon the incidental information as a clue to the answer. Students in the static-visual condition had no such incidental information on which to draw and were far less likely to commit to the misconception that heavy things fall at different rates than lighter things. These students had to base their answers on prior experience or guessing.

Researchers have found that novices tend to rely on superficial information as they attempt to solve a problem in a certain domain, whereas experts tend to categorize problems using only the most essential information necessary to form and test solutions (Chi, Feltovich, & Glaser, 1981). This implies that one tends to select and use cues that are actually more relevant to the problem as expertise in the domain increases. In other words, novices tend to organize solutions around superficial or surface-level information, whereas experts organize available information around only the essential underlying physical principles. Good problem solvers, such as experts, tend to appropriately select and link the most relevant information, whereas poor problem solvers, such as novices, do not (Eylon & Linn, 1988). In this study, novices seem to have used the surface-level information made available in the animated presentation to inappropriately link the two problem areas (Newton's second law and gravitation).

In addition, novices tend not to plan solutions very carefully, often choosing to commit prematurely to a solution early in the problem-solving process (Dalbey, Tourniaire, & Linn, 1986). It is probable that many of the students in this study who were presented with animated presentations maintained the animated sequence in their working memories and used it as a de facto strategy for solving the gravitation problems. Students may have seen a surface-level match between elements of the second law and gravitation problems and erroneously concluded that these were the same problem. Of course, this would not have happened unless the students had first properly extrapolated information that actually related to the Newton's second law problems. Having committed to the solution on the basis of the misconception on the immediate posttest, students persisted in their commitment to this solution on the delayed test.

The notion that students hold and maintain scientific misconceptions is not a new research issue (e.g., Perkins & Simmons, 1988). Research has shown that students form strong, though naive, personal theories, about the physical world, which are based on intuitive and frequently inaccurate models (Champagne, Klopfer, & Anderson, 1980). For example, it is commonly believed that students tend to hold an incorrect Aristotelian model of the physical world, in which moving objects slow down because they "run out of force." Some proponents of this view, most notably McCloskey (1983), have suggested that the instructional course of action is to force a theory change in students: from an Aristotelian theory to a Newtonian one, for example. This is accomplished by placing students in situations in which they are confronted by evidence that conflicts with their personal theories, thus exposing the falsehoods of their intuitive assumptions. Others who hold this belief, such as diSessa (1988), propose that students do not have a theory in any sense of the word, but rather claim ownership to a collection of knowledge fragments, some of which are seen by experts as correct and useful and others of which are seen as incorrect and detrimental. In contrast, these educators follow the instructional approach of capitalizing and building on the student's knowledge base to build "a new and deeper systematicity" (diSessa, 1988, p. 51) in which old knowledge is traded for new while a mental framework or model is constructed. In either case, problem solving will be influenced by a student's mental model of the task or domain. A mental model is a conceptual cognitive structure in a specific domain, such as physics, which a student develops and uses to explain general classes of problems (Eylon & Linn, 1988; Norman, 1983). Without an established and explicit mental model, students are likely to revert to misconceptions when solving novel problems, even though they may demonstrate mastery of specifically learned facts or procedures when tested. The unique aspect of this study is that it demonstrates that the external representations of instruction, animated displays in this case, may unwittingly contribute to both scientific accuracies and scientific misconceptions in the minds of students at the same time.

The second purpose of this study was to estimate the construct of intrinsic motivation as it relates to several practice activities that have proved to be effective in CBI in previous research: questioning strategies and structured simulations. Understanding whether certain activities have intrinsic motivating appeal is important when designing CBI. If activities contain such appeal, students will be more likely to maintain interest and stay on task for longer periods of time. This is because the focus of the reinforcement is internal, that is, students motivate themselves. This focus is in contrast to traditional CBI, which is largely based on behavioral designs, in which learning is believed to be the result of constant and appropriate external reinforcement. One can argue that internal reinforcers account for most informal daily learning such as that experienced through personal hobbies and interests. Designers of CBI practice activities have many strategies from which to choose. I argue that although several activities may promote similar performance levels, activities that are intrinsically motivating carry other significant advantages such as personal satisfaction, challenge, relevance, and promotion of a positive perspective on lifelong learning (cf. Keller & Suzuki, 1988; Kinzie, 1990). Previous research has used student free-choice patterns as a measure of continuing motivation (e.g., Kinzie & Sullivan, 1989). In this preliminary study, students overwhelmingly chose to return to the starship practice more often than questioning activities or even traditionally entertaining activities such as word-find puzzles, in support of the contention that the structured simulation carries intrinsically motivating appeal for students of this age. The structured simulation activity appears to possess many of the determinants of intrinsic motivation. The activity appears challenging but at a level that students can control. Students also seem to accept the premise that the activity is important and relevant because of the fact that the activity encourages them to accept and indulge in the fantasy of space flight. In this fantasy, they are not merely along for the ride, but are in charge of piloting the spaceship. I further contend that the activities, and not the computer, possess these characteristics. My contention is based on the finding that, of the other two choices, the paper-and-pencil activity was overwhelmingly chosen over the remaining computer activity (questions). A rival hypothesis is that the word-search puzzle activity lost its appeal by the time students were placed in the free-choice situation. If this were true, then, at the very least, the motivational characteristics of the simulation were more durable or sustaining than the puzzle activity. I encourage follow-up studies in which this durability hypothesis is tested by comparing these free-choice frequencies with choices of students who have initial exposure to the puzzle at the time that the first-choice activity data are collected.

Lastly, students in this study did not experience significant learning decay over the 2-day test–retest interval. Previous studies have indicated that picture effects are durable over long periods of time (Anglin, 1986; Peng & Levin, 1979). The results reported in this article support this contention.

In conclusion, this study has shown one example of the powerful ability of students to learn in incidental ways. Designers of CBI need to harness this ability by promoting it whenever possible while trying to avoid inappropriate student elaborations (such as misconceptions). One application of this research to the development of CBI may be the use of incidental information as an orienting activity for subsequent intentional instruction. More research is needed to extend these findings to other applications (such as far-transfer tasks) and content domains. More developmental research is also needed to understand how best to incorporate incidental-learning benefits into the design of CBI. Additionally, this study provides evidence to suggest that certain computer practice activities contain intrinsically motivating appeal for elementary school students. Future research should also be directed toward replicating these results in other contexts and content areas as well with learners with varying aptitudes and abilities. Taken together, these results support a philosophy of interdomain interaction and dependency. More research is needed that extends our understanding of how domains of learning influence each other.

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