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;

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