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Principles for using animation in computer-based instruction: theoretical heuristics for effective design

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Abstract

As tools for multimedia and computer-based instruction (CBI) increase in sophistication, it becomes easier for instructional designers to incorporate a range of animations in instructional software. Designers, however, should ask whether animation has the potential to contribute to student learning before investing the resources in development. This paper addresses the viability of using animations in multimedia and CBI. The functions of animations are explored as well as issues related to surface structure and fidelity. The relationship between content structures and the use of animation in CBI is also discussed. Based on these characteristics and purposes, heuristics are provided to guide the use of animation in CBI. Implications of these heuristics are explored and suggestions are provided for future research.

Computers provide innovative and efficient means for teaching students. As a result, various forms of computer-based instruction (CBI) and multimedia instruction provide a viable mode of teaching some content. One particularly promising capability provided is the ability to integrate animation as part of instruction. Authoring application programs have made animation readily accessible to any educator who has the patience to learn how to use the application (Sturman, 1998).

Unfortunately, the ease with which animation can be used has resulted in lessons that are superficially impressive but leave much to be desired in terms of their ability to be "instructive" (Large, 1996). There are three reasons for this superficial use of animation. First, while a plethora of articles empirically examine animation, little

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research results in principles guiding the use of animation. Second, the research that does exist is often highly theoretical and involves in-depth empirical methodology that is difficult for many practitioners to interpret. Third, a quick glance at the works cited in this paper will indicate a lack of accessibility for practitioners since much relevant research has been presented as either conference papers or in journals frequented solely by theoreticians—as opposed to practitioners.

Milheim (1993) attempted to improve the use of animation by offering application rules, but his article does not adequately account for contextual issues and idiosyncratic variables. In short, by offering product-based rules—as opposed to process-oriented guidelines—Milheim limits the degree to which his rules can be generalized to a variety of contexts. Large (1996) also attempted to theoretically frame the use of animation. He considers both empirical work and the methodological problems of researching animation, however, he does not offer practical guidelines for the use of animation. In contrast to these two papers, the current paper presents heuristics and practical advice for using animation in computer-based instruction.

There is a need for establishing design criteria for animations (Large, 1996; Mayer & Anderson, 1992). There is a need to move away from the "intuitive beliefs" and "trial and error" experiences of designers and develop sound principles for using animation (Hannafin, Phillips, & Tripp, 1986, p. 134). Specifically, this paper considers both the nature of animation and the nature of the subject matter as a basis for a heuristic that will help educators design effective animation within CBI. Within each section, implications for design are offered.

1. Nature of animation

The nature of animation is best described by examining its characteristics and purposes. First, animation is related to static visuals. Second, animation has a number of inherent purposes that a designer must consider. Third, there is a consideration of the physical attributes of animation. After a discussion of each of these features, implications for design will be discussed.

1.1. The relationship between animation and static visuals

To understand the nature of animation and its constructive use in CBI, designers must understand the relationship between animated visuals and static visuals. Animated visuals sometimes are considered a subset of visual graphics in general; thus, to some extent, the theoretical basis for using animation is the same as the theoretical basis for using pictures and other static visuals (Rieber, 1989; 1990a). This theoretical relationship has a basis in cognitive theory. For example, Pavio's (1986) dual coding theory, which argues that text and graphics are encoded in two different cognitive subsystems, seems to suggest that whether the graphics are static or animated is irrelevant. Thus, to some extent, theories of using graphics will apply to both animated and static graphics. In spite of some similarities between animated and static visuals, animation has the capability of demonstrating movement and trajectory; static visuals do not (Rieber, 1994). This difference in dynamics introduces certain aspects of animation that require special attention when used.

1.2. The inherent purposes of animation

Not only is the relationship between animated visuals and static visuals useful when considering the nature of animation, but also the purposes of animation are relevant to designers who are considering using animation in lessons. When animation is used in CBI, it should be used for specific purposes (Rieber, 1990a). Thus, designers should be familiar with the purposes of animation. The following paragraphs describe five functions of animation.

1.2.1. Cosmetic function

Still pictures can serve a decorative function in CBI (Levin, Anglin, & Carney, 1987). Similarly, animation can have a purely cosmetic function when it is used to make instruction attractive to learners. For example, special animated effects sometimes can dazzle and impress students in the opening title of a lesson.

Cosmetic applications of animation, however, do little to enhance learning. In fact, while cosmetics may have their place, they can distract learners from focusing on the main instructional points of a lesson. When the animation distracts from the learning task, learners misunderstand critical information. Thus, designers should exercise caution when using animation for a cosmetic purpose.

1.2.2. Attention gaining function

A second function of animations is their use to gain attention (Rieber, 1990a). Examples of this function include interesting special effects for transitions between instructional frames, screen washes, moving symbols or characters, and animated prompts. It is particularly important to gain the attention of learners at the beginning of a lesson (Gagné, 1985; Wilson, 1993). A second aspect of this function is to signal salient points such as switching topics. The movement created by the animation is useful for capturing the learner's attention and focusing it on the salient points.

This perspective is not universally accepted. Empiricism cannot sustain the notion that animation is a productive tool for keeping learners' attention once its "novelty" has become "mundane" (Large, 1996). Thus, the over-use of animation to gain learners' attention may not be beneficial.

1.2.3. Motivation function

A dancing bear, unicycle riding clown, or exploding fireworks used as feedback can motivate learners to strive for correct answers. Designers must exercise caution when using animation as a feedback mechanism. Surber and Leeder (1988) suggested the addition of feedback with "colorful graphic displays" does not enhance motivation. In fact, attractive animation that occurs when an incorrect answer is given may actually reinforce the wrong response. Thus, focusing on positive motivation through animation is particularly important.

1.2.4. Presentation function

The most direct application of animation is to use it as part of the presentation strategy. In general, animation can provide a concrete reference and a visual context for ideas (Knowlton, 1964). Since text illustrated with graphics is retained at a higher degree than text alone (Anglin, 1985, 1986; Anglin & Stevens, 1987; Mayer, 1989), one could argue that animation can improve retention of information due to the link between static and dynamic visuals. Even if rote retention is not the goal of a CBI, animation can help present information by defining a concept, rule, or step in a procedure. Animation also can supplement the text by providing examples of or elaborating upon a concept, procedure, or rule (Rieber, 1989). For example, an animated can-crushing demonstration was provided as an example of kinetic molecular theory (Sanger, Phelps, & Fienhold, 2000).

The use of animation as a presentation strategy is particularly helpful when presenting highly abstract or dynamic processes (DiSessa, 1982; Kaiser, Proffett, & Anderson, 1985; Rieber, 1990a, 1991). For example, animation might be particularly useful in helping students understand the flow of blood through the body.

1.2.5. Clarification function

While closely related to the presentation function, the clarification function employs animation to provide a conceptual understanding without providing new information. That is, the animation clarifies relationships through visual means. Animation can help clarify abstract relationships that might otherwise be difficult to understand. For example, in a computer-based economics lesson, the text might explain the relationship between the number of workers in a factory and the units of production that come off an assembly line. An animated plot graph might not add information, but it could clarify the accompanying text and help learners better grasp the relationship between the two variables.

1.3. The physical nature of animation

When considering the physical nature of animation, researchers and theorists have discussed many different characteristics. Color, pixel density, size, and degree of realism are a few variables that have been considered (Large, 1996). The surface structure and fidelity of animation are considered in the following heuristics. Both of these areas have implications for practitioners.

1.3.1. Surface structure

Surface structure is the "physical nature" of animation—texture and color, for example. Schnotz and Grzondziel (1996) demonstrated that the surface structure of a visual has a significant effect on the comprehension of the information taught. Details of the surface structure must be consistent within a computer-based lesson. For example, in the design of a chemistry microworld, the designer must use the standard colors used by chemists for oxygen and carbon molecules, as opposed to simply selecting colors that are visually pleasing. In addition, these elements must be represented consistently throughout the lesson. Using a nonstandard or an inconsistent representation could result in a stimulus conflict with the textbook for the learner and the need for additional cognitive processing to translate the identity of the molecules.

1.3.2. Fidelity level

Fidelity is related to realism (Park, 1994). If the fidelity level is too low—for example, in the case of slow motion or caricatured displays of computer graphics—learners may reach inaccurate conclusions regarding the effectiveness of motion. The fidelity level of the animation is a function of the task. High fidelity is not always cost effective or instructionally effective (Romiszowsky, 1993).

When considering fidelity, it is essential to distinguish between physical fidelity and functional fidelity. Physical fidelity considers how closely the animation resembles the real world. Functional fidelity reflects how closely the animation behaves like the real world object. Fidelity must be appropriate for the skills taught.

When designing an animation, the designer must consider the type of illustration to use. Research on static graphics has shown that abstract visuals are better retained in memory than concrete visuals (Smith & Smith, 1991). In other words, detail might confuse learners and make memory more difficult. A study (Schnotz & Grzondziel, 1996) comparing analogical and schematic illustrations found that schematic illustrations were retained significantly better than analogical illustrations. An analogical illustration refers to abstract concepts without literally identifying the concept. For example, an American flag conceptually portrays freedom. A schematic illustration is a literal representation of a concrete object (McAllister, 1991).

Making practical decisions about the fidelity of animation in CBI is dependent on the nature of the subject matter being taught, which is discussed in the next section of this paper. However, decisions can also be made based on the goals of the instruction. If the objective of the instruction is for learners to memorize information, abstract and schematic animation may be useful. On the other hand, if a broad, conceptual understanding is the objective of the instruction, students may benefit more from concrete and analogical animation.

1.4. Implications for design

The nature of animation has clear implications for the effective use of animation in CBI. Research results do not allow us to provide denotative rules for applying animation based on its nature; however, Fig. 1 can heuristically guide practitioners in considering the nature of animation.

Trajectory and movement are two inherent characteristics of animation. As Fig. 1 suggests, if trajectory and movement are not needed, animation might still be useful for cosmetic, attention getting, or motivational reasons. Ultimately, the need in a lesson for trajectory and movement are the only viable and substantive reason for using animation. That is, if trajectory and movement are inherently tied to the subject matter of a lesson, the incorporation of animation in a presentation or clarification function may enhance learning. If it does, both the fidelity and surface structure are important, but determining these elements is dependent on the subject matter of the lesson.

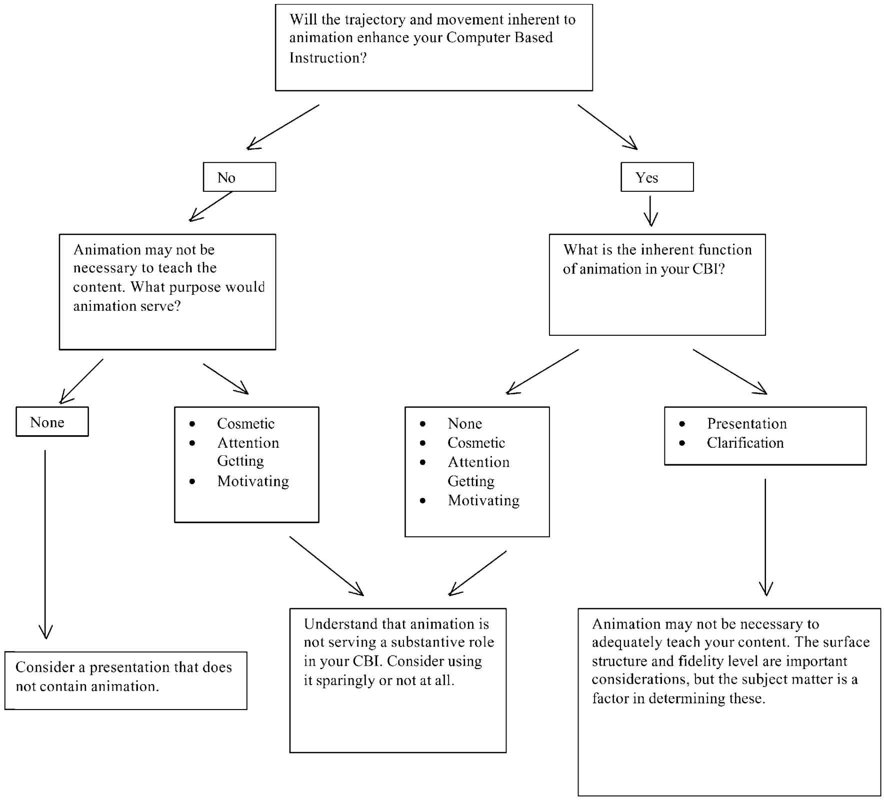

Fig. 1. The nature of animation: implications for design.

2. Nature of the subject matter

Indeed, some content areas and topics are more conducive to the use of animation than others. This assertion is not new (c.f. Large, 1996; Park, 1994; Rieber 1990a, 1990b, 1990c, 1994; Rieber & Kini, 1991), and a sound instructional design procedure for any format considers the subject matter. That is, the subject matter impacts the way a lesson should be designed (Morrison, Ross, & Kemp, 2001).

However, it should be noted that the classifications of subject matter and resulting decisions about the use of animation are not always clear-cut decisions. For example, Schnotz and Grzondziel (1996) conducted a study requiring students to solve problems related to time zone differences and circumnavigation problems. Interestingly, students using animated graphics performed better than the students using static visuals in answering questions regarding time differences, but the students using static visuals answered the circumnavigation questions better than the students using animated visuals. These results may seem counter-intuitive since the trajectory and movement inherent to these problems can be better communicated through the use of animation. The explanation offered by the authors for this difference was that the animated visuals—by their very nature—provided more information concerning time differences than the static visuals. By providing more information, the animation treatments made the circumnavigation aspect of the instruction easier to understand, resulting in less cognitive processing than required in solving the problems using static visuals. Less cognitive processing led to wrong answers.

The question as to whether it is best to make instruction as easy as possible requiring less cognitive processing or to write instruction requiring maximum cognitive processing is beyond the scope of this paper. Much additional research is needed to adequately address this question. Schnotz and Grzondziel's (1996) study does demonstrate that such decisions are difficult and the best of general heuristics cannot cover all potential exogenous theoretical questions.

In spite of these difficulties, a consideration of subject matter is essential to making decisions about animation's use in CBI. In the following section, we offer an explanation of where animation should be "placed"—regardless of subject matter. Next, we offer a classification of subject matter. Finally, implications for design will be offered.

2.1. Placement of animation with all subjects

Static visuals are more effective when accompanied by a verbal explanation (Mayer & Sims, 1994). This finding alone has implications for animation since there is a relationship between static visuals and animation. Mayer and Anderson's (1991, 1992) research seems to support the simultaneous presentation of text and animation. In a study comparing animated visuals with narration before, after, and during the animated illustration, Mayer and Anderson found that the most effective option was for the narration to be concurrent with the animation. Text-based narration is important in helping learners understand animation. If there is no explanation, or if the explanation is inadequate, the learner might fail to develop the appropriate understanding of the subject matter (Burke, Greenbowe, & Windschitl, 1998).

Beyond the issue of placement within subject matter is also the issue of "cueing." Rieber (1991) revealed that the effectiveness of animated visuals is reduced if the lesson insufficiently cues the learners' focus towards the information intended to be conveyed by the animation. The implication is that the designer must provide appropriate cueing to direct the learner's attention to animation. Miller's (1957) cue summation theory seems to support Rieber's cueing heuristic. Miller argued that simultaneous cues from different modalities support learning. One way to cue readers is through a simple narrative: "As you can see, the figure on the right simulates the movement of molecules under pressure." Beyond a narrative, an animation can cue itself if there is an abrupt movement or change that will attract the learner's attention.

These issues of placement and cueing cannot be ignored. From a practitioner's perspective, it is safest to present narration and animation concurrently. In addition, the narrative should actively cue learners' attention to the animation.

2.2. Classification of subject matter

The classification of subject matter—particularly when tied to a particular medium of delivery—is not a self-evident process. Rieber and Kini (1991), for example, argue that ‘‘changes over time’’ and ‘‘directional characteristics’’ are valuable classifications of subject matter when considering the use of animation. Morrison et al. (2001) offer a delineation of subject matter—referred to as ‘‘content structures’’. These structures are particularly useful for classifying the types of subject matter that might be found in CBI. Specifically, they argue for six structures: facts, concepts, principles or rules, procedures, interpersonal skills, and attitudes.

Concepts and procedures will be analyzed here as major categories of the heuristical process. Eliminating the other subject structures can be justified based on the assumptions of Rieber (1994), who supports the notion that ‘‘visualization research’’ should ‘‘go beyond investigating issues involving only recognition and recall tasks’’ (p. 149).

2.2.1. Concepts

The more complex a concept, the greater is the potential for animation to function in a clarification role. Park (1994) supports this argument by stating that if the content is too difficult to describe verbally, then animation can sometimes be used effectively.

Some situations that may be too difficult to describe verbally relate to changes that occur over time (Rieber, 1991). Trajectory and motion of various types can create these changes. In technical training animations are often used to illustrate a concept. For example, gas turbine engines use switches that when activated will stay on for a period of time and then shut down, or wait for a set time period after activation before turning the switch on. A graphic animation of these two concepts with a clock, switch, and motor can help the learner understand the differences between the two types of switches. The animation that illustrates the timer and delay periods that can help learners both see and understand the function of the concepts. This visual illustration makes the concept more distinct in the learner's minds by providing a concrete representation. These concrete representations can help students better express the concept. In one study, students who viewed an animated demonstration of a concept ‘‘were less likely to quote memorized mathematical relationships and... were better able to answer conceptual questions about the particular phenomena’’ (Sanger et al., 2000, p. 1519).

Animation can also be used to illustrate movements of a system normally not visible. Examples of this application include the flow of electrons in an electrical system, or chemical changes that result from experiments (c.f. Williamson & Abraham, 1995). Fleming, Hart, and Savage (2000) agree with this application of animation to present systems that are not normally visible. Such animation can help students create a ‘‘mental image’’ of the systems (p. 791). When the difference between two closely related concepts are not visible to the naked eye, animation can serve a clarification function. The animation can highlight key differences as a cue to help learners recognize the differences.

In other cases, animation can improve conceptual understanding of complex causal systems. Animation can help learners see how the manipulation of a variable impacts other variables. The gauges in an airplane are an example of this application since a gauge might respond to various influences and actions. While these influences and actions are not sequential, they do behave in a manner consistent with the real world. The simultaneous influences make animation even more useful in helping learners to understand the concepts being presented since humans tend to process information sequentially.

There are times when it is probably best *not* to use animated graphics to teach a concept. For example, if the subject matter is relatively simple, animated graphics do not improve learning compared with text only instruction (King, 1975). In fact, it is possible that animation may even have a distracting effect on the learner, since animation might make the concept more difficult.

2.2.2. Procedures

A procedure is "an ordered sequence of steps." An explanation of many procedures can be enhanced through the use of animation (Park, 1994). For example, animation may be particularly useful if the procedure involves equipment that is not readily available to the learner. Also, Park and Gittelman (1992) found that animation was effective for teaching trouble-shooting skills in electronic circuits. Animations are useful in simulating a context where procedures can be applied.

It should be noted that just as animation can have a detrimental effect in concept learning if the subject matter is simplistic, procedural learning can also be adversely effected if the subject matter is not difficult enough to require dual coding (Caraballo, 1985a, 1985b). That is, a relatively simple procedure can seem more complex than it really is when animation is used to explain the procedure.

2.3. Implications for design

Fig. 2 elaborates on implications for considering subject structures in designing animations in CBI. As Fig. 2 suggests, if animation can be used in a presentation or clarification role, the subject matter must be classified. Classification occurs in one of three categories. The first category includes facts, principles, and attitudes. The second category includes concepts. The final category includes subject matter that can best be classified as procedural. It is a classification of subject matter in one of these latter two categories that might indicate a need for animation.

For animation to be useful in the teaching of a concept, the concept should be relatively complex. That is, it should involve systems impacted by simultaneous influences, changes over time, or systems not visible to the naked eye. If the concept meets one of these criteria, animation might be useful in teaching the concept.

Fig. 2 also suggests that animation might be useful in helping learners grasp the steps of a procedure. This application is particularly useful when the procedure involves equipment that is not readily available or equipment that would be particularly costly to use. Also, animation can help simulate unusual conditions in which

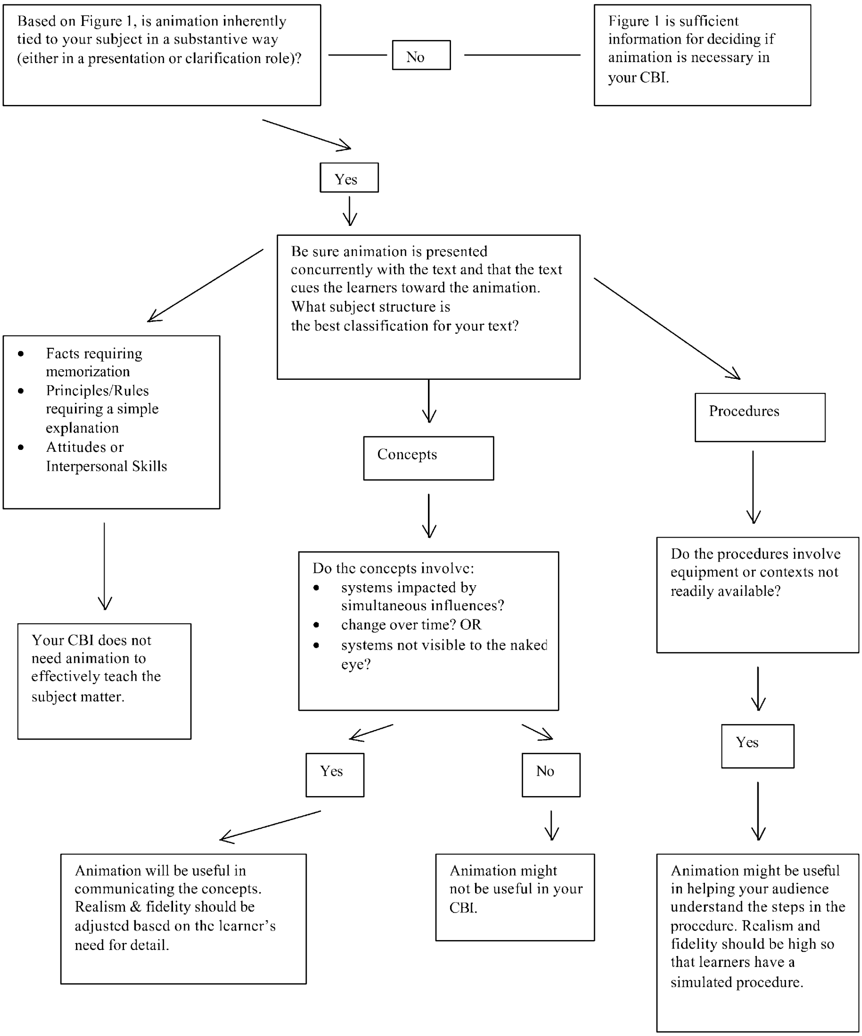

Fig. 2. The nature of the subject: implications for design.

procedures can be performed. In the case of procedures, realism and fidelity should be high so that learners have a simulated experience.

2.4. Recommendations for future research

In this paper we have offered practical heuristics for using animation in CBI. When applying these heuristics, designers should approach design as a non-linear, recursive, and iterative process. This "circular" nature of the heuristic is a strength to the extent that practitioners can check their decisions through more than one design criteria. But, research is needed on the way that designers understand the application process. Our heuristics offer guidelines for accomplishing the task, but they do not offer a step-by-step model of applying the heuristics. Case study research is needed to determine the way our heuristics are applied.

Our heuristics as a general foundation for a context adds credence to the need for case studies and other context-sensitive research. In other words, the heuristics are general but should be supplemented with an exact situation that a designer is trying to operate in. Research combining the heuristics with a specific design context could further supplement the design of instruction and thus the potential of student learning. For example, to a large extent the heuristics in the paper are based on literature from the hard sciences. By using this literature, we imply that principles for using animation in sciences are the same as principles in social sciences or even the humanities. More research is needed to make sure that our heuristics can cross discipline boundaries.

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