Animation: Does It Facilitate Learning?

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Abstract

Graphics, such as maps, have been used since ancient times to portray things that are inherently visual. More recently, graphics such as diagrams and graphs, have been used to portray things that are metaphorically spatio-visual. The assumption is that graphics facilitate comprehension, learning, memory, and inference. Assumptions aside, research on static graphics has shown that only carefully designed and appropriate graphics prove to be beneficial. Despite enthusiasm for animated graphics, the research reviewed here on their efficacy is not encouraging. In cases where animated graphics seemed superior to static ones, scrutiny of the actual stimuli revealed that the animated graphics conveyed more information, especially about the microsteps between larger steps. Lack of benefit from animations of events may be because animations are difficult to perceive and because events are often conceived of as sequences of discrete steps. Overall, this analysis suggests two principles, Apprehension and Expression, for successful animated graphics, though these principles do not guarantee that animated graphics will be superior to equivalent static ones.

Introduction: Graphics

Some uses of graphics

The enthusiasm for graphics of all kinds rests on the belief that they benefit comprehension and learning (some of the proponents include Larkin & Simon, 1987; Levie & Lentz, 1982; Levin & Mayer, 1993; Schnotz & Kulhavy, 1994; Tversky, 1995, in press; Winn, 1987, 1989). First, graphics may be aesthetically appealing or humorous, attracting attention and maintaining motivation. Next, graphics, as the saying goes, may save words by showing things that would otherwise need many words to describe. This is especially important for things like faces, maps, and systems that are naturally spatial and hard to describe or visualize. Graphics have been used since the beginnings of organized society to record information, historical, political, economic, and personal. Such records have appeared in myriad forms, including tallies, notches, and tokens (e. g., Gelb, 1963; Schmandt-Besserat, 1992). Yet another function of graphic displays is to use space to organize information and to facilitate memory. Computer menus are a familiar modern example, but using space to organize and remember is also an ancient practice (e. g., Bower, 1970; Small, 1997; Yates, 1969). Graphics can make internal knowledge external, available to a community to consider and revise. Finally, graphics have been used to promote inference and discovery by making the underlying structures and processes transparent (e. g., Bauer & Johnson-Laird, 1993; Dwyer, 1978; Larkin & Simon, 1987; Mayer, 1989; Tessler, Iwasaki, Kincho Law, 1995). Interestingly, for these purposes, simple graphics with less detail are often more effective than more realistic ones (e. g., Dwyer, 1978), provided that they abstract the essential conceptual information.

Visualizations of the visible and abstract

Graphic displays can be loosely divided into two kinds: those that portray things that are essentially visuospatial, like maps, molecules, and architectural drawings, and those that represent things that are not inherently visual, like organization charts, flow diagrams, and graphs. Graphics that portray essentially visual or spatial information have a clear and obvious advantage over other means of conveying that same information, notably language, in that they use space to convey space. In spite of the natural correspondences mapping space to space, there are situations where clear language is as effective as graphics (e. g., Taylor & Tversky, 1992). Graphics that portray things that are not inherently visuospatial rely on spatial metaphors. Pictorial elements can represent abstract meanings through "figures of depiction", for example, metonymy, where a concrete associate represents an abstract concept, such as the White House for the presidency or a pair of scissors for "delete". Spatial proximity is the basic metaphor underlying using space to express abstract relations. Closeness in space conveys closeness on some abstract dimension, such as time or causality (see, e.g., Tversky, 1995, in press). Graphics portraying things that are essentially visual are inventions that are ancient and widespread across many cultures. Graphics that use figures of depiction to convey abstract concepts are also ancient. In fact, the origins of written language can be traced to picture language. In contrast, graphics that use space to convey other relations are, for the most part, recent Western inventions (e. g., Beniger & Robyn, 1978; Carswell & Wickens, 1988; Tufte, 1983). Given that graphics can portray elements and relations that are not spatial as well as those that are spatial, their efficacy in learning and communication should be, and is, broad. In fact, it seems that it is difficult to capture the vast literature on effects of diagrams on learning with a summary less general than: graphics aid learning when they present the same information as text in a different format and also when they present information complementary to textual information (e.g. Levie & Lentz, 1982).

Natural cognitive correspondences in graphics

The benefits of graphics are apparent from their ubiquity and in their naturalness. By naturalness, we mean a convergence of inventions for using space to represent space as well as abstract concepts that suggest cognitive correspondences between mental spaces and real ones. The naturalness of using space and the things in it to express abstract concepts is attested by the invention and reinvention of similar graphics across cultures and ages. The pictorial languages and petroglyphs found all over the world are one example (e. g., Coulmas, 1989; DeFrancis, 1989; Gelb, 1963; Harley & Woodward, 1987, 1992; Mallery, 1893/1972; Woodward & Lewis, 1994). The manner of schematizing people, animals, rivers, mountains, foods, and houses bear striking similarities across cultures. Interestingly, these early written communications resemble contemporary attempts by preliterate children (Goodnow, 1977; Kellogg, 1969; Tolchinsky Landsman & Levin, 1987). Similarities in cross-cultural and developmental attempts to externalize mathematical concepts have been observed by Hughes (1986). For the most part, these graphic communications have used pictorial elements. Use of spatial relations to express temporal, quantitative, and preference relations was evident in children as young as 5 and in children from diverse cultures (Tversky, Kugelmass, & Winter, 1991). The use of space was systematic across young inventors who used primarily horizontal and vertical lines, with increases going upwards or to left or right. Inventors young and old naturally map increasing rates onto increasing slopes (Gattis, submitted; Gattis & Holyoak, 1996).

Graphics good and not so good

With recent rapid advances in technology and with increasing contact among cultures not sharing spoken languages, graphic devices have proliferated. However, the advances in the technology of producing attractive graphics often seem to drive and outstrip the development of tools and devices rather than research on their utility. Graphics are not always effective, or put differently, not all graphics are effective in all situations. In fact, the early research comparing learning with graphics to learning with text alone gave mixed results, often in spite of enthusiasm for the pictorial devices (see reviews by Levie & Lentz, 1982; Levin & Lesgold, 1978; Mandl & Levin, 1989). Moreover, much of the early research used global comparisons between media and did not address the subtler questions of what accounts for facilitation when it occurred. As research progressed, the types of situations, graphics, tasks, and learners for which graphics are effective has become clearer. Three-dimensional displays are a new case in point. They seem to be everywhere, or at least in software packages, and they do seem to be liked (Carswell, Frankenberger, & Bernhard, 1991; Levy, Zacks, Tversky, & Schiano, 1996). However, it is simply not clear if 3D displays improve performance, speed, accuracy, or memory for data (Carswell, et al., 1991; Levy, et al., 1996; Spence & Lewandowsky, 1991). In some tasks, for example, memory, there is little difference between 3D and 2D displays; in other tasks, for example, estimation, there is a disadvantage to 3D displays (Zacks, Levy, Tversky, & Schiano, 1998).

Animation

Another of the newer, attractive graphic devices is animation. On the surface, animation is compelling. In principle, it should be a natural for conveying concepts of change, just as space in graphics is a natural for conveying actual space. Animation should, in principle, be effective for expressing processes such as weather patterns or circuit diagrams or the circulatory system or the mechanics of a bicycle pump. And, just as real space is effective for conveying metaphoric space, real change should be a natural for conveying metaphoric change, such as the spread of cultural inventions like writing, agriculture or metallurgy, the transmission of control in an organization, or the changes in production of various industries over time. Given the breadth of concepts for which animation is appropriate and the increasing accessibility of computer tools for animating, the enthusiasm for animation is understandable.

Preview

With this background on graphics in mind, we will selectively review research on animation. "Selectively" because some of what has been called animation has involved other aspects of communication situations, especially interactivity, which is known to benefit learners on its own. To evaluate animation per se, it must be compared to graphics that do not change with time, as it is change with time that animation adds. This review will not provide encouragement for the enthusiasm for animation. That leaves us with a need to explain why animation has not produced the expected benefits. To account for the failures of animation, we step back and take a closer look at how people perceive and comprehend real animations. With human perceptual and cognitive limitations in mind, we turn again to the basic question: when will animation be effective?

Kinds of animations

Of course, change over time can be viewed in many different ways, hence conveyed by animations differing in complexity. Perhaps the simplest movement is a path or trajectory. This can be animated as the movement of a dot, providing that the features of the moving object are not relevant. Representing the speed and manner of the moving object may require enriched animations. Sometimes what needs to be conveyed is more complex than a path, for example, the movement of parts of an object or system with respect to each other. The movement or change of either a path or a system may be in two or three dimensions. In these cases, movement is of the object or system itself. In other cases, the object or system may be stationary, and the movement of the viewpoint of the observer, to show other aspects of the object or system. The critical information to be conveyed determines the form of the animation. But whatever the form, in order to be effective, an animation must be perceived and comprehended adequately. Clearly, complexity challenges comprehension.

Selective Review of Research on Animation

One of the most elegant uses of animation is a pair of moving dashed lines to illustrate differences in speed (Baek & Layne, 1988). In this animation, the irrelevant aspects of the situation had been eliminated, and the essential aspects reduced to dots moving proportional to speed. Although students learning from the animation outperformed those learning from a static diagram, little can be concluded. The static diagram did not take advantage of spatial distance to convey problem distance, so there is no way of knowing if the animated graphic produced benefits beyond a comparable static graphic (see Figure 1).

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  I- - - - - - -I- - - - - - I
  I<-180 miles->I<-69 miles->I distance
  I<-   6   hours   ->I<-   3   hours->I
travelling
                                time
```

Figure 1: An example static graphic from Baek and Layne's (1988) experiment. The animated graphic showed the animation of the dash line, - , at speeds proportional to the travelling times depicted. In this example, the line was animated for 12 seconds for the 6 hour travelling time and for 6 seconds for the 3 hour travelling time.

Lack of comparability of static and animated diagrams obviate conclusions about the benefits of animation in other studies. In a study evaluating graphics for teaching the circulatory system, the animated diagrams of the heart included blood pathways, but the static diagram did not (Large, Beheshti, Breuleux, & Renaud, 1996). The static graphics used in Rieber's (1990, 1991a, 1991b) computer-based lesson on Newton's laws of motion did not include information fundamental to understanding the laws. As can be seen in Figure 2, the static graphic for Newton's law of equal and opposite forces depicts the movement of the ball, but not the information that kicks to the ball start and stop its motion. The concept of inertia is critical to understanding this law, yet can only be extracted from the accompanying text. The animated diagram, in contrast, showed that the foot kicks were responsible for the starting and stopping of the ball's motion. Although both Large and his colleagues and Rieber believe their findings support the use of animated graphics, the differences between the static and animated graphics call this conclusion into question.

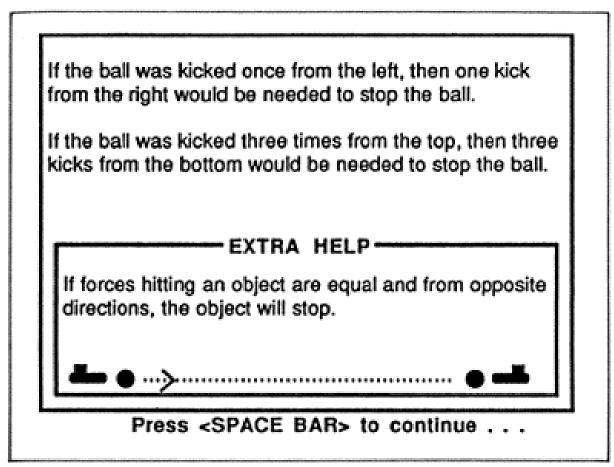

Figure 2: Example static diagram from Rieber's (1989) computer-based lesson on Newton's laws of motion.

At first glance, for some of the studies evaluating static and animated graphics, the graphics appear comparable. But on close examination, the animated graphics present information not available in the static versions, in particular the details of the microsteps between larger steps, that is the minute spatial-temporal actions of components. Events such as those portrayed in animations can be segmented into coarser and finer units by observers (Zacks, Tverksy, & Iyer, submitted). For the most part, the coarse units segment by object or object parts and the fine units segment by fine-grained actions on the same part. Many of the static graphic displays portray the coarse segments whereas the animations portray both the coarse and fine segments. Thus, there is greater information in the animations than in the static displays.

In a study evaluating students' ability to learn the operation and troubleshooting of an electronic circuit from a static graphic or from an animated graphic, Park and Gittelman (1992) report better performance in the animated graphic condition. Although both graphics, static and animated, showed the relationships between components in the process, only the animated graphic showed the microsteps. Specifically, when an action was taken with the circuit, the animation depicted the fine-grained actions of the components. The static graphic showed the spatial relationships among the components but did not display the mechanics of the circuit's response to a particular action and the consequent change in the circuit state.

Similarly, Lee's (1997) static graphic presentation of the steps in the operation of a bicycle tire pump failed to include the microstep information available in the animated presentation, for example, the exact temporal relations between the movement of the handle and the opening of the valve. The static graphics were eight screen shots with arrows depicting the movements of the pump parts and the motion of air through the pump (see Figure 3). The animated graphics were a continuous demonstration of pump’s operation, providing information not available in the static diagrams.

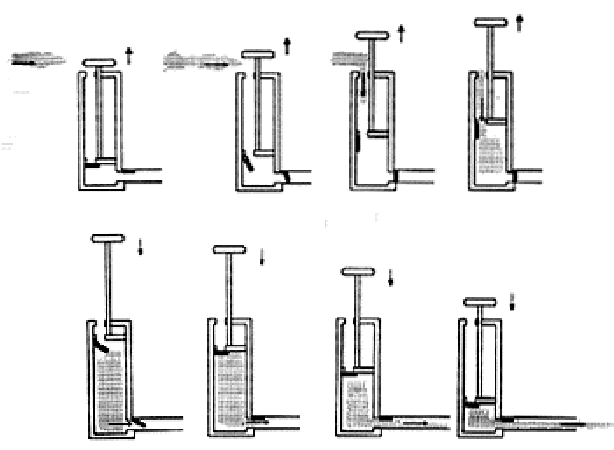

Figure 3: Eight Steps in the Operation of a Bicycle Tire Pump. These eight diagrams were used by Lee (1997) to teach students the operation of a bicycle tire pump.

Research by Thompson and Riding (1990) further supports the hypothesis that animation facilitates learning when it presents the microsteps of processes that static graphics do not present. Their lesson taught the Pythagorean theorem to junior high school students. The lesson showed the use of shears and rotations to depict the equivalence of area of three different figures. One group received a paper with a static graphic (see Figure 4), a second group saw a discrete animation of the steps shown on the paper graphic, and a third group saw a continuous animation of the steps. The group viewing the continuous animation outperformed the other two graphic groups. The authors explicitly state that the information on the paper graphic was equivalent to the discrete animation, but not equivalent to the continuous animation. The continuous animation depicted all the microsteps, while that information had to be inferred from both of the other graphics.

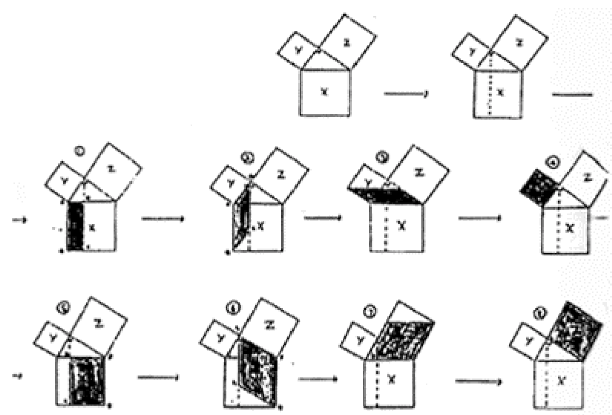

Figure 4: Thompson & Riding's (1990) Shears and Rotations Diagram.

The lack of equivalent information in static and animated graphics is not the only difficulty in evaluating possible benefits from animation. Other studies comparing animation have not used equivalent procedures. Kieras (1992) investigated the effects of animated and static graphics on students’ ability to understand the operation of an energy system, the "Star Trek Phaser Bank". Students studied conceptual information about the system in the form of text or in the form of static or animated diagrammatic information. Students who learned from the animated graphic performed significantly better on the firing the phaser and diagnosing malfunctions tasks than those who learned from a static graphic or lacked a graphic. Students with the static or animated graphics, however, were allowed to use the graphics during the test phase of the experiment. The presence of graphics during the test phase makes the task one of reading graphics rather than using the information contained in the graphics. That is, the animated graphic may be facilitating execution of the task rather than understanding of the task.

Nathan, Kintsch, and Young’s (1992) Animate program is an animated interactive program used to help students with word problem comprehension, in particular, distance equals rate times time equations. The program is designed to allow students to develop an understanding which relates the formal mathematics of a word problem to the situation described in the problem. Students in the Animate condition wrote a formal equation to solve the problem and then animated the equation to see if it depicted the expected solution. None of the other conditions included graphics and two of the three conditions had interfaces substantially different from the Animate interface. Although performance in the Animate condition was better than in the other three conditions, the lack of comparability among conditions does not allow any conclusions about the relative efficacy of animated graphics.

On closer inspection, then, many of the so-called successful applications of animation turn out to be a consequence of a superior visualization for the animated than the static case, or to other uncontrolled factors. In addition the literature is filled with outright failures to find benefits of animation. Rieber and Hannafin (1988) and Rieber (1989) found no effects of animation’s effectiveness in teaching Newton’s laws of motion to elementary school students. In one case animation was used as an orienting activity prior to the presentation of each section of the lesson (Rieber & Hannafin, 1988). In the second case, elaborating the textual lesson with additional text and/or no, static, or animated graphics did not lead to performance differences (Rieber, 1989). Rieber, Boyce, and Assad (1990) used the same design to evaluate the performance of college students when learning Newton's laws. As with the earlier experiments there was no effect of graphic condition. Additionally, providing different forms of practice, one involving interactive animation, had no effect in any of the three experiments.

Students learning about the production of growth hormones during biotechnology were presented with text alone, a static diagram, or an animated diagram (ChanLin, 1998). When learning procedural information, such as the formation of a peptide chain, the students viewed a single static diagram which combined information about all the steps in the process. Students in the animation group viewed a series of individual animations depicting each step of the process. Students in both conditions performed equally well. In fact, the only difference found was between the static and no diagram condition for those students who had a background in biology. All other conditions, for both biology and non-biology students, were equal in terms of performance.

As a supplement to a biology course they were taking, junior high students interacted with the Advanced Computing for Science Education (ACSE) environment which is a multimedia program incorporating textual information, still graphics, movies, and simulations (Pane, Corbett, & John, 1996). Students using the ACSE program did not perform better than students using static graphics except for a slight advantage for information presented only in the ACSE program.

Byrne, Catrambone, and Stasko (under review) tested the effectiveness of animated graphics in teaching college students computer algorithms, specifically depth-first searches and binomial heaps. The authors were discouraged to find that the benefits of viewing animated graphics were equivalent to making predictions about the outcomes of the algorithms when provided with static graphics.

Animated graphics are often employed to teach students how to use a computer or a computer program. This is also an area where these animations do not appear to be effective. Three groups of researchers investigated using animation to teach students how to use a Macintosh computer, how to use the MacDraw Graphics editor, and how to use Hypercard (Dyck, 1995; Payne, Chesworth, & Hill, 1992; Harrison, 1995, respectively). In each case, presenting any type of a graphic, static (only for Harrison, 1995) or animated, facilitated performance when compared to providing no instruction. Students in the animated graphic conditions did not outperform the those in the equivalent text (Dyck, 1995; Payne, Chesworth, & Hill, 1992) or static graphic (Harrison, 1995) conditions.

Palmiter and colleagues compared animated and still graphics when teaching students how to use an on-line help system for Hypercard (Palmiter, Elkerton, & Baggett, 1991, Palmiter & Elkerton, 1993). Although the students completed the training task more quickly when using the animation, they completed the testing task more slowly. Moreover, after a week, students who had studied the text improved in their performance, but students who had studied the animation declined. The long-term facilitation of text over animation was attributed to deeper processing of the text than of the animation.

Thus, most of the successes of animation seem to be due to the extra information they convey, rather than the animation of that information. Animations are often interactive; interactivity is know to facilitate performance but it should not be confused with animation (e.g., Ferguson & Hegarty, 1995). Finally, animations are thought to be attractive and motivating, so they could be preferred just for that (Perez & White, 1985; Rieber, 1991a; Sirikasem & Shebilske, 1991). However, it turns out that animations frequently take more time, so they have a cost. Even more damaging to the motivation hypothesis is that animations are not universally preferred, and are often not used (e.g., Pane, Corbett, & John, 1996).

How are animations perceived and conceived?

The many failures to find benefits of animation even in conveying change over time, a concept that seems ideally suited to animation is surprising, indeed, disappointing, and calls for deeper inquiry into information processing of animation. The drawback of animation may not be the cognitive correspondences between the conceptual material and the visual situation but rather perceptual and cognitive limitations in processing a changing visual situation.

Perception of animation

Generations of paintings in galleries and museums all over the world portray the legs of galloping horses incorrectly. Before stop-gap photography, the complex interaction of horses legs simply happened too fast to be accurately apprehended. Even when motion is simplified to the path or trajectory of a single object rather than the complex interaction of moving parts, perception of motion may not be accurate. Sketches of the trajectories of pendula, propelled objects, and dropped objects by novices and experts alike are often incorrect, apparently governed more by Gestalt-like perceptual principles than laws of physics (e. g., Caramazza, McCloskey, & Green, 1981; Freyd & Jones, 1994; Kaiser, Proffitt, Whelan, & Hecht, 1992; McCloskey, 1983a, 1983b). Paths of moving objects, for example, are perceived as closer to horizontal or vertical than they actually are (Pani, Jeffres, Shippey, & Schwartz, 1996; Shiffrar & Shepard, 1991). For some kinds of motion, observers can select the correct path from an animation, but still reproduce it incorrectly (Kaiser, et al., 1992).

Comprehension of animation

Even when actual motion is smooth and continuous, people may conceive of it as composed of discrete steps (e.g., Hegarty, 1992; Zacks, Tversky, & Iyer (submitted); but see Schwartz, 1999, Schwartz & Black, 1996, for evidence that for atomic substeps that are analog in nature, such as the turning of gears, mental animation may be analog as well). If motion is conceived of in discrete steps instead of continuously, then the natural way of conveying it may be to portray it in discrete steps rather than in a continuous animation. This is quite common in pictorial instructions for complex motion, such as operating a machine or assembling an object, where each step is portrayed in a separate frame and the frames ordered by the sequence of steps. For simple motion, as in the path of an object or the flow of control or electricity through a system, a single diagram can convey the path, indicated by lines and arrows. In addition to corresponding to the way people conceive of animations, these diagrammatic devices have an additional advantage: they easily allow comparison and reinspection of the details of the actions. By contrast, animations are fleeting, they disappear, and when they can be reinspected, they must usually be reinspecting in motion, where it may be difficult to perceive all the minute changes simultaneously.

Conclusion

By now, the failures to find beneficial effects of animation over equivalent static diagrams is not surprising. For the few successes, the animated graphics in fact were not equivalent to the static graphics. In some of the most carefully controlled cases, the animations conveyed detailed information about the microsteps. It may be that this sort of information is more easily conveyed in animations than in static diagrams, and that would be sufficient reason for using them. However, in many other cases animations may have failed because they were difficult to perceive or because they mismatched people's conceptions of motion, which are often discrete rather than continuous.

This analysis suggests two principles specifying conditions for successful animated graphics, though these principles do not guarantee that animated graphics will be superior to equivalent static ones.

- Principle of Apprehension: Animation must be readily perceived and comprehended.
- Principle of Expression: Conceptual knowledge to be conveyed must be apparent from animation.

Even if both of these conditions are fulfilled, it remains to be seen whether animations will prove to be more valuable than comparable still diagrams.

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