

Animations: A key advance for open and distance learning?

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Explanatory graphics are increasingly pervasive in online and other electronic learning environments. Static and animated graphics are especially attractive to those producing resources for the international education context. While use of a specific written or spoken verbal language may be an impediment to learning, graphics are widely regarded as universally accessible. They also have the potential to address aspects of learning that are particularly challenging for open and distance education. Traditional approaches based largely on textual information can be poorly suited to the learning of subject matter that is intrinsically visual in nature. Further, for content dealing with change over time (such as processes and procedures), static forms of information may be ill-matched to the learning task. In contrast, animated graphics offer a very direct way to explain topics that are both highly visual and intrinsically dynamic. Animations can be regarded as a way to overcome previous limitations inherent in open and distance learning. One possibility is that courses previously requiring a significant on-campus component for aspects involving processes and procedures could instead now be presented largely online. Current practice in online learning suggests that conventional wisdom assumes animated graphics to be intrinsically superior to both text and static graphics for the presentation of dynamic subject matter. However, quite contrary evidence is emerging from recent research on learning from animations. This paper examines the perceptual and cognitive challenges faced by learners when they interact with animations and presents research-based recommendations for improving the design quality and educational effectiveness of dynamic visualisations.

Text, graphics, or animation?

Verbal forms of information have long dominated formal education. With the spoken or written word traditionally given the primary responsibility for presenting to-be-learned content, graphics have tended to play a secondary role as adjuncts to that verbal information. However, this traditional relationship between verbal and graphic information is undergoing a profound change. Of particular importance are advances in information and communications technology coupled with the development of powerful graphics processing software. As a result of this progress, static and animated graphics are an increasingly pervasive feature of online learning environments. In the context of web-based learning resources, the ready availability of graphics has led to them being given more and more responsibility for content presentation. Subject matter that only a few years ago was presented almost exclusively via verbal information is now far more likely to be offered in a multimedia format that makes extensive use of explanatory graphics. One reason for this swing towards graphics is undoubtedly the attraction they hold for a generation of learners who have been raised in a visually-oriented society. For these learners, the affective impact of graphics can be considerable in terms of their initial engagement with the presented material and the sustaining of their motivation.

There is little doubt that screen after screen of uninterrupted text has far less appeal to today's learners than displays that make extensive use of graphics. However, in addition to these affective benefits, graphics also have the potential to facilitate various perceptual and cognitive

process that are necessary for learning to occur once engagement and motivation have been secured. There is a conviction among many designers and developers of educational materials that graphics make their own unique contribution to the effectiveness of learning because of the particular way they present visual and spatial information. Traditional approaches to education based largely on verbal presentation of information are poorly suited to this purpose. There has also been rising interest from researchers in how learners comprehend graphics (e.g., Schnotz & Kulhavy, 1994). Unlike verbal presentations, graphics can present such information in a way that closely corresponds to the visuospatial structure of the referent subject matter. Graphic representations can play an external role that supports internal cognitive processes (Hegarty, 2004; Scaife & Rogers, 1996). They offer advantages over a verbal alternative for processes such as search and the establishment of relationships (Larkin & Simon, 1987). Further, when graphic representations are used in conjunction with verbal information, learning can be facilitated due to the multimedia effect (Mayer, 2003). There is a need for a more sophisticated approach to how people learn from text and visual displays, particularly in the way that information from these two very different sources is integrating during learning (Schnotz, 2002).

In many disciplines, much of the information that learners must deal with has an important dynamic component because it involves processes and procedures. Multimedia learning resources increasingly include dynamic subject matter and there is growing research interest in finding robust principles that might guide their design (Narayanan & Hegarty, 2002; Moreno, in press). Until very recently, the presentation of dynamic subject matter for distance and flexible learners has been particularly challenging, particularly when visual, spatial, and temporal dimensions of the content are all important. Verbal representation of such information struggles to cope with the visual and spatial aspects while static graphics often handle the dynamics poorly. Ancillary markings such as arrows and dotted lines may be incorporated in static graphics in an attempt to convey dynamic information. However, these additions tend to clutter the depiction and must be properly interpreted in order to understand the changes being represented. During this interpretation process, it is assumed that the learner constructs a mental model of the situation depicted (Johnson-Laird, 1983) and that this must include dynamic information about how the situation changes over time. This mental model building activity must be carried out within the constraints of the limited capacities that humans have for processing information. If a learner cannot interpret the ancillary dynamic markings on a static graphic, or interprets them wrongly, an inappropriate mental model will result and learning will be compromised. Animations obviate the need for these markings and their attendant disadvantages for learners. It therefore seems reasonable that animated explanations are replacing static graphics in open and distance learning contexts.

The animation advantage

The property of animations that most obviously distinguishes them from static graphics is their capacity to provide a direct depiction of change over time. In many cases there is a simple correspondence between the dynamics of the original subject matter and the changes depicted in its animated representation. From an educational point of view, this directness removes the need for learners to carry out the cognitive manipulation (i.e., mental animation) that is assumed to be required with static depictions of dynamic subject matter (Hegarty, 1992). Mental animation of the information shown in a static graphic can be a demanding process, particularly when the represented content is complex or unfamiliar. There are also individual differences in the capacity to perform mental animation (Hegarty & Sims, 1994). Learners who have low spatial abilities are especially likely to have difficulties in carrying out appropriate mental animation from a static graphic.

Even when graphic cues about the dynamic character of the subject matter are provided in a static graphic, mental animation may still be challenging and prone to error. This is because the process of converting the single image into a continuous visual representation can rely heavily on inference about details of the dynamics involved. The ancillary graphic markings that are used to indicate dynamics on a static graphic are inevitably rather crude indicators of the actually changes involved. For example, while an arrow may show the general direction an entity moves, it is difficult to simultaneously indicate other important aspects of the change, such as speed variations, etc. It is even harder for a static graphic to depict dynamics effectively

when multiple entities are undergoing change, particularly if these changes are interrelated in subtle ways.

Animations appear to provide a superior alternative to static graphics for depicting dynamic subject matter. The dynamic properties of animations can be used to mirror behaviours of the referents being depicted. Representation of those dynamics by animation is explicit so they are directly available to learners via perception without the need for the additional and often demanding cognitive processing that is required with a static depiction. More of the learner's limited cognitive capacity is therefore available to be used for the central task of understanding the depicted content (as opposed to the peripheral task of trying to work out how the subject matter behaves). Because animations provide dynamic information directly, the learner's task is limited to interpreting the exhibited behaviour.

Challenges for learners

From the previous discussion, it may seem that animations should be far more effective than static graphics in supporting the learning of dynamic subject matter. However, there is an increasing questioning of conventional wisdom about the superiority of animated graphics (Tversky, Morrison, & Betrancourt, 2002). It appears that potential benefits of animated depictions must be traded off against a number of challenges that animation can pose for learners. These challenges are concerned with limits on our human capacities to process the types of information contained in animations and how animations present that information to the learner (Lowe, 1999). When the depicted subject matter is unfamiliar to the target learners, such challenges can be particularly acute because these learners lack the domain knowledge that would allow them to chunk the presented information for efficient processing. Compared with the 'single frame' of a static graphic, the multiple frames of an animation present a greater total amount of information that the learner must process. Further, this greater information load must be processed under a strict time regime because if the animation's frames are presented too slowly, the illusion of movement is lost. This means that each frame is available to the learner for only a fraction of a second. While such limited processing time may not be a problem for very simple subject matter, more complex information is unlikely to be processed adequately under these conditions.

The overall complexity of an animation has much to do with the graphic entities that are used in the display and the ways in which those entities are related. Animations presenting a host of varied entities that are connected by a myriad of relationships are likely to be especially demanding for the learner. Not only are the constituent entities invariably distributed around the display, but their locations also often change during the course of the presentation. In addition, the changes that are relevant to understanding the relationships between these entities may occur simultaneously in different parts of the display. In order to build an understanding of the subject matter depicted by the animation, the learner must attend to these distributed items of information and attempt to link them into a coherent whole. Because our visual system is limited to focusing on very small area of foveal vision at a time, it is impossible for the learner to perceive all aspects of a complex changing display at once. Rather, the display must be explored and information extracted incrementally. It is therefore unrealistic to expect learners to cope with a complex animation at a single viewing, particularly if they are novices with respect to the subject matter depicted.

So, what approaches could designers of educational animations adopt in order to help learners manage such complexity? It is tempting to think that interactive animations may be the answer (c.f. Bétrancourt, in press). However, even when learners are provided with a user-controllable animation that may be repeatedly and freely interrogated, there is no guarantee that they will be able to extract the required information (Lowe, 2004). Rather, a *perceptual dominance* effect may prevail in which graphic material that is highly conspicuous but not necessarily of particular relevance to the learning task can preferentially capture learner attention while more important information is neglected (Lowe & Schnotz, in press). While the visuospatial properties of the entities in an animation provide one set of characteristics that can contribute to whether or not information is noticed, temporal properties may also be important (Lowe, 2000). In particular, perceptibility appears to be influenced by the extent to which *dynamic contrast* is present between a graphic entity and its surrounding context. For example, rapidly moving entities on a

relatively unmoving background are likely to receive preferential attention. However, the fastest moving entities may not necessarily be the most important in terms of the current learning task. Graphic entities used to depict the subject matter represented by an animation can be either static or dynamic. In many cases, static graphic entities in the animation serve a contextual function as the background to the dynamic graphic elements that show how the subject matter changes with respect to its form or position. A necessary consequence of using animated graphics to depict change over time is that some aspects of the information they present are transitory. The dynamic graphic entities typically undergo one or more of three main types of change (Lowe, 2003): *translation* (in which a graphic entity moves within the animation display area), *transformation* (in which the graphic entity changes with respect to its form (shape, size, colour, texture, etc.), and *transition* (in which the graphic entity appears in, or disappears from, the display area). For example, an animated ball may bounce around inside the frame (translation), grow, change colour, and morph into a square (transformation), then exit from the frame (transition). The fleeting nature of animation means that for a single-play animation, information presented earlier in the animation is no longer directly available at a later stage. This contrasts markedly with the situation for a static graphic in which all information is permanently accessible. As a result, earlier information must be held in the learner's memory if it is needed at a later stage of the animation. This is a problem not only because the learner may be unable to appreciate the significance of information at an early stage in the presentation, but also because later information effectively overwrites earlier information in the learner's working memory.

The dynamic character of animations appears to have a seductive effect on those who design educational materials. Many designers prefer animated depictions over the static alternatives and, for some, this is probably because of the affective impact animations are presumed to have on learners. However, other designers appear to prefer animations because of their capacity to represent dynamics in a direct, explicit manner. There is a tendency for the flood of animations that have appeared in electronic learning materials in the last few years to focus on presenting the dynamics of the subject matter in as realistic a manner as possible. This *behavioural realism* is employed even when the depiction is highly diagrammatic in character rather than having a realistic appearance. Such animations present the dynamics in all their complexity with no concession made to the information processing demands that result. With animated diagrams, it can be interesting to contrast the extremely unrealistic abstraction used for the visuospatial aspects of the subject matter (i.e., its appearance) with the slavishly authentic depiction of its behaviour.

Design recommendations

Researchers have so far failed to find any general educational advantage for animations over static graphics. While this appears to be counter-intuitive, it can perhaps be explained in terms of inadequacies of current animation design. At present, animations are designed and developed largely on the basis of intuition rather than research-based principles. This current situation is partly a result of the lack of existing research on how people learn (and don't learn) from animation. Systematic research into what happens when learners interact with educational animations is in its infancy and only in the last few years have useful findings started to emerge from empirical studies. Nevertheless, there is now a sufficient body of research evidence to allow a number of general design recommendations to be offered. The following suggestions are made on the basis of the limited amount of research evidence currently available.

First, a clear distinction should be drawn between possible affective and cognitive functions of animation in supporting learning (Lowe & Schnotz, in press). If these two purposes are not clearly delineated, the animation's effectiveness may be compromised because of conflict between features designed to grab attention and aspects that are concerned with developing a full and coherent understanding of the subject matter. Because the perceptual characteristics of animations can be such a powerful influence on what learners notice and connect, designs that emphasise affective impact over cognitive considerations may lead to important aspects of the subject matter being neglected.

Second, key aspects of the subject matter need to be portrayed in such a way that the learner's attention is specifically directed towards them as required. This means the display should be manipulated in ways that change the perceptual salience of the various information components in order to emphasise important features and de-emphasise less important ones. Manipulation of perceptibility needs to occur throughout the course of the animation and it may well be that entities highlighted during one period are suppressed during another. The cueing of thematically relevant aspects within an animation is particularly crucial for learners who are relatively unfamiliar with the subject matter. Such learners will lack knowledge about what areas of the display are likely to contain important information and at what periods during the animation those areas should be inspected (Lowe, in preparation).

Third, the current preoccupation of designers with producing behaviourally realistic animations seems seriously misguided, especially when the subject matter involves complex dynamics. The processing demands that are involved in dealing with changes depicted as they actually occur may simply overwhelm the learner with information. As a result, key information is likely to be missed so that comprehension suffers. Designers can learn a great deal from the approaches that have evolved over the years for producing educationally effective static graphics.

Manipulation of information has long been standard practice for educational illustrations. Simplification and the gradual build up of information is a feature of these illustrations and similar approaches could well be adapted to the design of animation.

Fourth, animations should not be expected to function effectively in isolation. Rather they generally need various types of support (c.f. Mayer & Anderson, 1991), an idea that contrasts markedly with the widely held view of animations as adjuncts to text. Instead, it may be more effective to reverse this usual relationship and cast text (or at least verbal information) in the role of adjunct to animation. Given that complex animations can place heavy processing demands on the learner's visual system, it is usually wise not to exacerbate this situation by adding on-screen text in an attempt to support the graphic information. However, because narration utilises a different and non-visual processing channel, it is usually better to accompany animations with verbal rather than visual information.

Conclusion

Animations are a potentially valuable tool for open and distance learning. However, current approaches are unlikely to realise this potential because they rely on animations that tend to be designed on the basis of intuition rather than research-based principles. Further, even well-designed animations may be ineffective if the target learners lack the domain-specific background knowledge necessary for appropriate processing of the presented content. Research on how animations are processed is beginning to show the complexity of this activity and the varied demands it makes on learners. It is becoming clear that many animations are far from 'self-explanatory' but instead may require that the learner is given significant support and guidance for them to be effective. Other more traditional resources, such as verbal exposition, offer many possibilities for increasing the effectiveness of animation as a tool for learning. We already have the technology required to generate and distribute animations to open and distance education students. The advance we need now is for animations to be designed and presented in ways that can make the best of the opportunities this technology provides.

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