The animation and interactivity principles in multimedia learning

Article · January 2005

DOI: 10.1017/CBO9780511816819.019

Mireille Bétrancourt
University of Geneva

Chapter 18. The Animation and Interactivity Principles in Multimedia Learning

Mireille Betrancourt

TECFA

Geneva University

Mireille.Betrancourt@tecfa.unige.ch

Phone: +41 22 379 93 71

Fax: +41 22 379 93 79

Chapter proposed to R.E. Mayer (Ed.) **The Cambridge Handbook of Multimedia Learning**.

Chapter 18. The Animation and Interactivity Principles in Multimedia Learning

Mireille Betrancourt

Abstract

Computer animation has a tremendous potential to provide visualizations of dynamic phenomena that involve change over time (e.g., biological processes, physical phenomena, mechanical devices, historical development). However, the research reviewed in this chapter showed that learners did not systematically take advantage of animated graphics in terms of memorization and comprehension of the underlying causal or functional model. This chapter reviewed the literature about the interface and content features that affect the potential benefits of animation over static graphics. Finally, I proposed some guidelines that designers should consider when designing multimedia instruction including animation.

What Are the Animation Principle and the Interactivity Principle?

In the last decade, with the rapid progression of computing capacities and the progress of graphic design technologies, multimedia learning environments have evolved from sequential static text and picture frames to increasing sophisticated visualizations. Two characteristics appear to be essential to instruction designers and practitioners: the use of animated graphics as soon as depiction of dynamic system is involved, and the capability for learners to interact with the instructional material.

Conceptions of animation. Despite its extensive use in instructional material, computer animation still is not well understood. Baek and Layne (1988) defined animation as "*the process of generating a series of frames containing an object or objects so that each frame appears as an alteration of the previous frame in order to show motion*" (p. 132). Gonzales

(1996) proposed a broader definition of animation as "*a series of varying images presented dynamically according to user action in ways that help the user to perceive a continuous change over time and develop a more appropriate mental model of the task*" (p. 27). This definition however contained the idea that the user interacts with the display (even minimally by hitting any key). In this chapter we do not restrict animation to interactive graphics, and choose Betrancourt and Tversky's (2000) definition: "*computer animation refers to any application which generates a series of frames, so that each frame appears as an alteration of the previous one, and where the sequence of frames is determined either by the designer or the user*" (p 313). This definition is broader by design than either of the preceding definition. It does not stipulate what the animation is supposed to convey, and it separates the issue of animation from the issue of interaction.

According to Schnotz and Lowe (2003), the concept of animation can be characterized using three different levels of analysis: Technical, semiotic and psychological. The technical level refers to the technical devices used as the producers and carriers of dynamic signs. With the evolution of the computer graphics industry, distinguishing between events captured by way of a camera or events completely generated by computer is becoming harder and irrelevant to learning issues. Second, there is a semiotic level, which refers to the type of sign, that is the kind of dynamics that is conveyed in the representation. This includes concerns about what is changing in the animation and how (e.g., motion, transformation, changing of points of view). Third, there is a psychological level, which refers to the perceptual and cognitive processes involved when animations are observed and understood by learners. Discussions about the design of animation often focus on technical or surface characteristics. From a learning perspective, issues regarding realism, 3-dimensionality, or abstraction are important only insofar as they change the way the content to be learned is going to be perceived and apprehended by learners.

Conceptions of interactivity

First of all, a clear distinction should be made between two kinds of interactivity: control and interactive behavior. In this chapter we do not consider that control and interactive behavior are different degrees on the same scale but rather are two different dimensions. Whereas control is the capacity of learner to act upon the pace and direction of the succession of frames (e.g., pause-play, rewind, forward, fast forward, fast rewind, step by step, and direct access to the desired frame), interactivity is defined as the capability to act on what will appear on the next frame by action on parameters. In this case animation becomes a simulation of a dynamic system in which some rules have been implemented. Simulations are not be the focus of this chapter and are mentioned as a specific feature of animation (for more details on simulation, see chapter 33). For purposes of this chapter, interactivity is meant as control over the pace of animation.

Examples of scenario using animation and interactivity

The main concern for instructional designers and educational practitioners can be summarized by the simple question: When and how should animation be used to improve learning? Three main uses of animations in learning situations can be distinguished.

Supporting the visualization and the mental representation process

The first situation is not substantially different from the situations in which graphics are used: Animation provides a visualization of a dynamic phenomenon, when it is not easily observable in real space and time scales (e.g., plaques tectonics, circulatory system, or weather maps), when the real phenomenon is practically impossible to realize in a learning situation (too dangerous or too costly), or when it is not inherently visual (e.g., electrical circuit, expansion of writing over times, or representation of forces). In this perspective, animation is not opposed to static graphics but to the observation of the real phenomenon.

For example, we used an animation to explain an astronomic phenomenon (the transit of Venus) and particularly why it occurs irregularly (Rebetez, Sangin, Betrancourt & Dillenbourg, 2004). This animation was design following Narayanan and Hegarty's (2002) principles. The instruction first depicted the three objects involved (i.e., Earth, Venus, and the sun) and their relative motion. In order to understand the phenomenon, two frames of reference alternate: a galactic view point (the planets are seen from outside the solar system) and an earth view (in order to see Venus's trajectory on the sun as seen from the earth). The animation was segmented in 16 frames, the sequence of which was under learner's control. An aural commentary was provided synchronized with the animation.

Producing a cognitive conflict

Animation can be used to visualize phenomena that are not spontaneously conceived the way they are in the scientific domain. For example, there are many situations in physics in which naïve conceptions dominate over the scientific conceptions (e.g. the fact that objects of same volume and different weights fall at the same speed, or the trajectory of falling objects from moving objects). In this case an instructional scenario can provide several animations of the same phenomenon and ask the learner to pick up the correct situation. Kaiser, Proffitt, Whelan and Hecht (1992) used such situations, but though learners recognized the correct animation, they were still unable to produce in a drawing the correct trajectory afterwards. A scenario that includes groups of learners viewing and discussing the animations could improve learning in encouraging learners to make their conceptions explicit.

Enabling learners to explore a phenomenon

In this third use, the learner actively explores the animation in order to understand and memorize the phenomenon. Here interactivity is a key factor. It can be a simple VCR control on the pace and direction of the animation with a suitable learning activity. But it can include a high degree of interactivity with a learning task that encourages learners to generate hypotheses and test them by manipulating the parameters. In this case the animation becomes a simulation that is used in a discovery-learning approach.

Whatever the function animation serves, it can include several level of interactivity form the simple “resume” function, to complete learner control over the pace and direction of the animation. Roughly speaking, complete control should benefit advanced learners more than beginners, since it supposes that learners have the capability to monitor their inspection of the animation. Another feature of interactivity that can be incorporated into an animation is the possibility to change the view point. Changing viewpoint enables learners to explore the phenomenon from different perspectives, similar to those that would be available to an active, moving observer. Though this feature is not difficult to implement, it is hardly used in multimedia instructions, but is extensively used in video games.

Review of Research on Animation and Interactivity

It seems reasonable to assume that providing a visualization of what “really” happens in a dynamic system will facilitate learners’ comprehension of the functioning of the system. Space in graphics is used to convey spatial and functional relations between objects, which are directly perceived by learners whereas they must be inferred from verbal information. Similarly temporal changes in animations make temporal information directly perceivable by learners whereas they must be inferred from static graphics. However, as with the research on the effect of pictures in text, the research on animation yields mixed and contradictory results, with actual effects of animation ranging from highly beneficial to detrimental to learning. The question whether animation is more effective than static graphics can not been answered in the general case. Rather the question should be: *when* and *why* is animation more effective than static graphics?

In many cases, animation does not add any benefit compared with static graphics, even when the content involved change over time (Betrancourt & Tversky, 2000; Tversky, Bauer-Morrison and Betrancourt, 2002). For example, Narayanan and Hegarty (2002) report studies on learning in the domain of mechanics in which animation could be expected to improve understanding of novices, since the behavior of the system is not predictable from naïve conceptions. In one experiment, they compared two hypermedia and two printed versions of instruction about the functioning of flushing cistern: The first hypermedia was designed following guidelines deriving from a cognitive model of multimedia comprehension (Hegarty, Quilici, Narayanan, Holmquist, & Moreno, 1999); the second hypermedia instruction was a commercially available products. The two hypermedia instructions were compared to printed versions of either the cognitively designed hypermedia material or the commercial product. Both hypermedia instructions included animated and interactive graphics. Participants spent the time they wanted studying one of the four presentations. Then they were asked to write a causal description of how the device works and two answer comprehension questions about the functioning of the system. The results showed that participants studying with the cognitively designed material outperformed participants studying with the commercial product on all comprehension measures. However, there was no difference in comprehension between the cognitively designed hypermedia and its printed version. In other words, animated and interactive graphics did not improve comprehension compared with their static equivalents. Moreover, students in the hypermedia conditions did not rate the material as more interesting than students in the paper conditions. We may think that the benefits of animation would appear more clearly when the domain is abstract in nature, like computer algorithms or physics concept. In a lesson designed for elementary school students explaining Newton's laws of motion animation did not lead to better comprehension scores though motion is an essentially dynamic concept (Rieber and Hannafin, 1988; Rieber, 1989). Using an instructional material explaining computer algorithms, that are known to be difficult for students to comprehend, Catrambone and Fleming Seay (2002) found that animation had a positive impact on performances in difficult transfer problems, but that the benefits of animation disappeared when the accompanying text was carefully designed to provide all the critical information.

When animation provides benefits over static graphics, it may be due to interactivity in the animated graphics, with the system reacting according to learner's input (what we defined here as a simulation). In this case, the animation leads the learner to make predictions about the behavior of the system, which can in itself improve deep understanding. Using instructional material on computer algorithms, Byrne, Catrambone and Stasko (1999) found that the benefits of using animation was equivalent to the benefits of prompting learners to make predictions, and that the two effects were not cumulative. The same results were obtained with mechanical systems (Hegarty, Narayanan and Freitas, 2002; Hegarty, Kriz and Cate, 2003): Participants who studied the animation with oral commentary did not get better comprehension scores than those who studied equivalent static graphics with written text, but those who were asked questions that induced them to predict the behavior of the system had better understanding of the device than those who were not asked prediction questions.

Two main explanations related to the way human perceive and conceive of dynamic information may account for the failure of animation to benefit. First, human perceptual equipment is not very efficacious regarding processing of temporally changing animation. Though we track motion quite automatically, we are very poor in mentally simulating real trajectories (Kaiser *et al.* 1992). Second, even when actual motion is smooth and continuous, people may conceive of it as composed of discrete steps (Hegarty, 1992; Zacks, Tversky & Iyer, 2001). For example, the functioning of the four-stroke engine is in most mechanical handbooks represented by a static picture of each of the four steps. If dynamic systems are conceived of a series of discrete steps, giving an animation will not make comprehension easier than a series of static graphics. In learning how a flushing cistern works, Hegarty, *et al.* (2003) found that an animation did not lead to better understanding than a series of three static diagrams representing phases of the system, both conditions being more beneficial than one static diagram of the system. However, animation is the only way to represent transitions between the discrete steps in a dynamic system and remains necessary for learners who are not able to mentally simulate the functioning of the system from static graphics (which Schnotz (2002) called the enabling function of animation). Rebetez *et al.* (2004) showed that a continuous (but learner controllable) animation led to better comprehension performance than a succession of static snapshots for instructional materials explaining geological and astronomic phenomena when learners were in pairs (Figure 1).

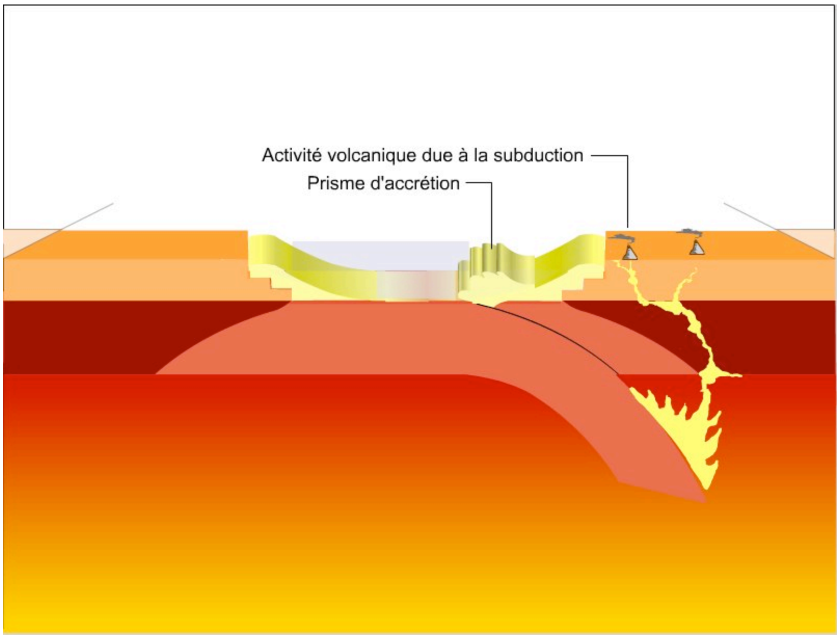

Figure 1 – Snapshot of the instructional material on subduction used in Rebetez *et al.* (2004).

Interactivity may overcome these perceptual and conceptual obstacles. Control over pace and direction could be considered as a simple surface feature at the interface level, which would hardly affect learners' motivation. Research showed however that learners in control of the pace of the animation not only find the material more enjoyable but also perform better tests of deep learning than learners who have no control of animation. This gain has been found even when control was minimal such as deciding when to run the next sequence (Mayer & Chandler, 2001). Control can thus overcome perceptual limitations, since the presence of pauses in the animation enables learners to process the continuous flow of information without perceptual and conceptual overload. New information can be processed and integrated progressively in the mental model (Mayer & Chandler, 2001). Moreover, learners who have complete control over the pace and direction of the animation can monitor the cognitive resources (e.g., attention and processing) they allocate to each part of the animation. Schwan and his colleagues (Schwan, Garsoffky & Hesse, 2000; Schwan & Riempp, 2004) showed that users who were in control of the pace and direction of a video spent more time on difficult parts of the video.

Another concern is the need to provide segmentation in order to help learners conceptualize the functioning of the system. A direct way to convey segmentation in the animation is to insert a pause after each main phase. According to this conception, learners should benefit more from computer-paced than user-paced control device. The research shows that users who had partial of full control over the animation performed better in post-test than users who had no control (Mayer & Chandler, 2001), but results are scarce and inconsistent regarding the gain of having full control. Preliminary research showed that in most cases novice learners do not have the knowledge to identify the most relevant parts of the animation and do not monitor the control very effectively (Lowe, 2003; Kettanurak, Ramamurthy & Haseman, 2001).

What Are the Limitations of Research on Animation and Interactivity?

The effect of using animated displays with or without interactivity has mostly been investigated in laboratory experiments with the traditional mental model paradigm, involving studying the material and then answering explicit and transfer questions in a posttest with little or no delay. The effect of animation over longer retention intervals has hardly been investigated, primarily for practical reasons (e.g., engaging participants to come back one or several weeks later, or ensuring that they did not study the material by themselves in the meantime). Similarly, studies on animation in real learning settings and using rigorous experimental methods are scarce. Though such studies could provide interesting and ecological results, it should be made sure that the animated and non- animated situations are equivalent with all other respects, especially the attitude of the teacher or trainer and the learning activities.

Research carried out from a cognitive perspective has not shown much consideration for the kind of learning material. Designing an animation--like designing graphics--requires decisions on the way objects, motion and other non visual features (force, speed, etc.) are represented. Animation involves in most cases a mixture of representational features, which bear a resemblance to the real object, of domain-specific or common conventional signs and symbols (e.g. arrows) and, of primary importance, of verbal information. As some format factors have multimedia instructional value, the semiotic information conveyed by representational, symbolic, and verbal information and their relationships probably affect the way learners process the material. At least designers should ensure contiguity between verbal and graphic information, use signaling to reinforce important information and logical links and provide commentary in the aural modality (see Chapter 12x,y and z).

Other determinants of the effectiveness of animation that seem of primary importance but are scarcely investigated are individual differences in expertise in the domain and visuo-spatial abilities. Generally, benefits due to the instructional format are greater for novices than experts (e.g. Mayer & Sims, 1994). Experts, who have already formed mental models in the domain, can rely on long-term memory processes to learn about complex phenomena. In some cases, providing animation to learners who are able to mentally animate the system is detrimental to learning since it induces a shallow processing of the material (Schnotz, Boeckheler and Gzrondziel, 1999; Schnotz & Lowe, 2003). Conversely, animation indices a complex visual processing and may be beneficial only to learners with high visuo-spatial abilities (Mayer & Sims, 1994). Studies are needed to confirm these results in a large variety of learning tasks and objectives, which could help designers to adapt the instructional material to the targeted learners.

Finally the research has mostly studied the effect of animation on off-line learning outcomes, but little is known on the way people explore and process animation, though it can have direct implications for design. Lowe (2003) showed that novices focused their attention on perceptually salient rather than thematically relevant features of the animation. To lower this tendency the design of the animation should include devices that guide learners' attention to important features of the animation such as arrows or visual highlighting.

Implication for Cognitive Theory

As Schnotz (2003) stated, three functions can be attributed to animations with regard to the elaboration of a mental model of a dynamic system: *enabling, facilitating or inhibiting functions*. When learners are novices or have poor imagery capabilities, animations enable learners to visualize the system that otherwise they would not be able to mentally simulate. Second, even when learners are capable of mentally simulating a dynamic system, providing animation can lower the cognitive cost of mental simulation thus saving cognitive resources for learning. The formation of a "runnable" mental model of the system (Mayer, 1989) is then facilitated. However, as animation saves learners from mentally simulating the functioning of the system, it may induce a shallow processing of the animated content, and consequently leads to what can be called the "illusion of understanding". Then the elaboration of a mental model is inhibited by animation. This obstacle can be avoided by designing carefully the instructional situation, in which learners are engaged in active processing while viewing the animated document.

Animation appears as a paradigm to investigate what is a "runnable mental model": is it a succession of steps that may be hierarchically organized (Zacks, Tversky & Iyer, 2001; Hegarty, 1992) or a kind of mental simulation of the system? To generate inferences from the mental model, do learners base their reasoning on static states of the system and the combination of rules, or do they mentally run the system and inspect it? In the latter case, animation would help the formation of the model, but in the first case, static representation of essential steps and knowledge of rules would suit better. A promising research track involves studying on-line processing of animation through qualitative data (self-confrontation methods in ecological situations) in relation to more classical measures of learning performance (Lowe, 2003; 2004).

Implications for Instructional Design

Animations are attractive and intrinsically motivating for learners. However, they are hard to perceive and conceive, their processing requires a heavy cognitive load and there is chance that learners do not get any benefit from studying the animation compared with static graphics.

To use or not to use animation

In this context, and given the cost of designing animated graphics compared to static ones, the first question an instructional designer should ask is "Do I really need to use animation?". According to the research on animation, animation should be used only when needed, that is when it is quite clear that learners will benefit from an animation. Two conditions are:(1) When the concept or phenomenon depicted in the animation involves change over time and that it can be assumed that learners would not be able to infer the transitions between static depictions of the steps. If animation is used when it is not really needed from a cognitive point of view, learners will process a material that is complex but not directly useful for understanding how the phenomenon works. Mayer, Heiser and Lonn (2001) have shown that learning is impaired when non-relevant material is added (see *coherence principle*, chapter 12, this volume).

(2) When learners are novices of the domain, so they cannot form a mental model of the phenomenon (*enabling function*) or are faced with a very high cognitive load (*facilitating function*).

If learners are able to mentally simulate the phenomenon given a reasonable mental effort, providing them with an animation will prevent them from performing the mental simulation of the system, thus leading to a shallow processing of the graphic matter. In this case animation is not beneficial and even can impair learning (*inhibiting function* mentioned in Schnotz, 2002).

Instructional Implications

The effect of using animated display is often investigated in laboratory experiments with the traditional mental model paradigm, involving studying the material and then answering explicit and transfer questions. From a designer or practitioner point of view, some reflection is needed on pedagogical uses of animation. Three main uses of animations in learning situations can be distinguished:

- Supporting the visualization and the mental representation process: From a pedagogical perspective, animation is not opposed to static graphics but to the observation of the real phenomenon. With an enabling or facilitating cognitive function according to the level of expertise of learners, animation can be used to visualize a dynamic phenomenon when it is not easily perceptible (space and time scale), when the real phenomenon is practically impossible to realize in a learning situation (too dangerous or too expensive) or when the phenomenon is not inherently visual (representation of abstract concept such as forces).
- To produce a cognitive conflict: animation can be used to visualize phenomena that are not spontaneously conceived the right way. We could cite many situations in physics in which naïve conceptions dominate over the scientific conceptions (e.g., the fact that object of same volume and different weights fall at the same speed, or the trajectory of falling objects from moving platforms). In this case using several animations of the correct and false response could help learners to make their conceptions explicit.
- To have learners explore a phenomenon: here interactivity is a key factor. It can be a simple VCR control on the pace and direction of the animation with a suitable learning activity. But it can include a high degree of interactivity with a learning task that

encourages learners to generate hypotheses and test them by manipulating the parameters. In this case the animation becomes a simulation that is used in a discovery-learning approach.

6.2. Design principles of the instructional animation

Given that the content is appropriate, five design principles can be derived from the research, besides the contiguity principle, modality principle and signaling principle described in Chapters 11 and 12.

- *Apprehension principle* (Tversky *et al.*, 2002): The external characteristics should be directly perceived and apprehended by learners. In other words, the graphic design of objects depicted in the animation follow the conventional graphic representation in the domain. This principle also recommends that any additional cosmetic feature that is not directly useful for understanding should be banished from animation. For example, 3D graphics should be avoided as should bi-dimensional motion or change in the display. Similarly, realism is not necessary when the point is to understand the functioning of a system or to distinguish its parts.
- *Congruence principle*: Changes in the animation should map changes in the conceptual model rather than changes in the behavior of the phenomenon. In other word, the realism of the depicted phenomenon can be distorted if it helps understanding the cause-effect relationships between events in the system. For example, in mechanics, events that occur simultaneously can be successive in the chain of causality (e.g. a valve opens and the water flows in). In this case, it should be better to represent the two events successively in the animation, so that the learners can build a functional mental model of the display.

- *Interactivity principle*: The information depicted in the animation is better comprehended if the device gives learners the control over the pace of the animation. This can be a simple “Resume” function in a pre-segmented animation, which has be shown to improve learning (Mayer & Chandler, 2001). Not only this simple control gives learners time to integrate information before proceeding to the next frame, but also it segments the animation into relevant chunks. The addition of a higher degree of control (traditional functions of a VCR) should be used when it can be assumed that learners have the capabilities of monitoring the cognitive resources they should allocate to each phase of the animation. In Schwan’s *et al.* (2000) study, learners could evaluate their needs since they could mimic the procedure of tying the knot. Conversely, Lowe (2003) showed that learners were not able to evaluate the most conceptually relevant parts of animation but that they rather focused on perceptually salient features.
- *Attention-guiding principle*: As animation is fleeting by nature, often involving several simultaneous changes in the display, it is very important to guide learners in their processing of the animation so that they do not miss the change. Moreover, Lowe (2003) showed that learners' attention is driven by perceptually salient features rather than thematically relevant changes, simply because novice learners are not able to distinguish between relevant and irrelevant features. To direct learners’ attention to specific parts of the display, designers can use signaling in the verbal commentary (see Signaling principle, in Chapter 12) and graphic devices (e.g., arrows or highlights) that appear close to the element under focus.
- *Flexibility principle*: As it is not often possible to know in advance the actual level of knowledge of learners, multimedia instructional material should include some options to activate the animation. Then information provided in the animation should be clearly described to avoid redundancy between the static and animated visual material.

Animation has a tremendous potential to improve understanding of dynamic information such as trajectories, transformations or relative motions, both in physical domains (e.g., biology, mechanics, geology) and abstract domains (e.g. electric or magnetic forces, computer algorithms). However the research rarely found benefit from having animation compared with traditional and "low cost" instructions. In this chapter I mentioned the available guidelines both on the content and design levels that designers should keep in mind when planning to use animation. Further research is needed to fully understand "when" animation should be used and "how" it should be designed to promote learning.

References

Baek, Y. K. & Layne, B. H. (1988). Color, graphics, and animation in a computer-assisted learning tutorial lesson. *Journal of Computer-Based Instruction,* **15,** 131–135.

Betrancourt and Tversky (2000). Effect of computer animation on users' performance: a review. *Le travail Humain*, **63**, 311–330.

Byrne, M. D., Catrambone, R. & Stasko, J. T. (1999). Evaluating animations as student aids in learning computer algorithms. *Computers & Education*, **33**, 253–278.

Catrambone, R. and Fleming Seay, A. (2002). Using animation to help students learn computer algorithms. *Human Factors*, 44, 495–511.

Gonzales, C. (1996). Does animation in user interfaces improve decision making? in *Proceedings of Computer Human Interaction, CHI'96* (Vancouver, April 1996), ACM Press, 27–34

Hegarty, M. (1992). Mental animation : Inferring motion from static displays of mechanical systems. Journal of experimental psychology : Learning, Memory and *Cognition*, **18** (**5**), 1084–1102.

Hegarty M., Kriz S. and Cate C. (2003). The roles of mental animations and external animations in understanding mechanical systems. *Cognition and Instruction*, **2**, 325–360.

Hegarty, M., Narayanan, N. H. & Freitas, P. (2002). Understanding machines from multimedia and hypermedia presentations. In J. Otero, J. A. Leon & A. Graesser, Eds. *The Psychology of Science Text Comprehension*, pp. 357–384. Hillsdale, NJ: Lawrence Erlbaum.

Hegarty, M., Quilici, J., Narayanan, N. H., Holmquist, S. & Moreno, R. (1999). Designing multimedia manuals that explain how machines work: Lessons from evaluation of a theory-based design. *Journal of Educational Multimedia and Hypermedia*, **8**, 119–150.

Kaiser, M. K., Proffitt, D. R.,Whelan, S. M. & Hecht, H. (1992). Influence of animation on dynamical judgments. *Journal of Experimental Psychology: Human Perception and Performance*, **18**, 669–690.

Kettanurak, V. N., Ramamurthy, K. & Haseman, D. (2001). User attitude as a mediator of learning performance improvement in an interactive multimedia environment: an empirical investigation of the degree of interactivity and learning styles. *International Journal of Human-Computer Studies*, **54**, 541–583.

Lowe, R. K. (2003). Animation and learning: selective processing of information in dynamic graphics. *Learning and Instruction*, **13**, 247–262.

Lowe, R. K. (2004). Interrogation of a dynamic visualization during learning. *Learning and Instruction*,**14**, 257–274.

Mayer, R.E. & Chandler, P. (2001). When learning is just a click away: Does simple interaction foster deeper understanding of multimedia messages? *Journal of Educational Psychology*, **93**, 390–397.

Mayer, R.E. & Sims, K. (1994). For whom is a picture worth a thousand words ? Extensions of a dual-coding theory of multi-media learning. *Journal of Educational Psychology*, **86**, 389–401.

Mayer, R.E., Heiser, J. and Lonn, S. (2001). Cognitive constraints on Multimedia learning: When presenting more material results in less understanding. *Journal of Educational Psychology*, **93**, 187–198.

Narayanan, N.H. & Hegarty, M. (2002). Multimedia design for communication of dynamic information. International *Journal of Human-Computer Studies*, **57,** 279–315.

Rebetez, C., Sangin, M., Betrancourt, M., & Dillenbourg, P. (2004). Effects of collaboration in the context of learning from animations, in *Proceedings of EARLI SIG meeting on Comprehension of Text and Graphics: Basic and applied issues*, 9-11 September 2004, Valencia (Spain), 187–192.

Rieber, L. P. (1989). The effects of computer animated elaboration strategies and practice on factual and application learning in an elementary science lesson. *Journal of Educational Computing Research*, **5**, 431–444.

Rieber, L. P. & Hannafin, M. J. (1988). Effects of textual and animated orienting activities and practice on learning from computer-based instruction. *Computers in the Schools*, **5**, 77–89.

Schnotz, W. (2002). Enabling, Facilitating, and Inhibiting Effects in Learning from Animated Pictures. Paper presented at the Dynamic Visualizations workshop, Knowledge Media Research Centre, Tübingen.

Schnotz, W., & Lowe, R.K. (2003). External and internal representations in multimedia learning. *Learning and Instruction*. **13**, 117–123.

Schnotz, W., Boeckheler, J., & Grzondziel, H. (1999). Individual and co-operative learning with interactive animated pictures. *European Journal of Psychology of Education*, **14**, 245–265.

Schwan, S., Garsoffky, B. & Hesse, F.W. (2000). Do film cuts facilitate the perceptual and cognitive organization of activity sequences ? *Memory and Cognition*, **28**, 214–223.

Schwan, S. & Riempp, R. (2004). The cognitive benefits of interactive videos: learning to tie nautical knots. *Learning and Instruction*,**14**, 293–305.

Tversky, B. Bauer-Morrison, J., & Betrancourt, M. (2002) Animation: Can it facilitate? *International Journal of Human-Computer Studies*, **57**, 247–262.

Zacks, J., Tversky, B . & Iyer, G. (2001). Perceiving, remembering, and communicating structure in events. *Journal of Experimental Psychology: General*, **130**, 29–58.

Glossary

Animation: animation refers to any application that generates a series of frames, so that each frame appears as an alteration of the previous one, and in which the sequence of frames is determined either by the designer or the user.

Dynamic information: information that involves a change over time, such as translations (trajectories, motions), transformation (deformation, relative positions and actions) and progression (adjunction or subtraction of elements).

Control: the possibility for the learner to act upon the pace and/or the direction of the succession of frames in a multimedia presentation.

Interactivity: the possibility for the learner to act upon what will appear on the next frame by action on parameters (e.g., by clicking directly on sensitive areas or by scaling up and down cursors) in a multimedia presentation.