The Role of Static and Animated Pictures That Complement Texts in Supporting Learning

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Abstract: Pictures are widely used to accompany texts as adjuncts to facilitate learning. This article discusses the role of such a combination in supporting learning and the underlying theory that explains how individuals process visual and verbal information and how they can benefit from such a combination. It is hypothesized that the facilitative effect of picture-text combination is attributed to the supportive role of pictures played in the cognitive processing involved in mental model building of the situation being explained.

Key words: static pictures, animated pictures, mental model.

Teaching/learning resources (from textbooks to computer-based instruction) typically contain texts accompanied by pictures. However, the question arises as to the contribution these pictures make in supporting learning. The contribution of pictures to learning seem to be taken for granted by those who produce the resources. Some research findings indicate that pictures may not always be as effective as their widespread use would seem to suggest. Further, there is a lack of principled guidance for the design, choice, and use of pictures that are intended to complement texts. These activities tend currently to be carried out largely on the basis of intuition and past practice. Educators need to know what types of pictorial support are most likely to be helpful.

As well as the pictures found in textbooks and other resources, teachers often use additional pictures to complement their teaching. This reliance on pictures reflects an implicit assumption by practitioners that these visual representations are intrinsically effective in supporting learning. However, the question arises as to how useful these pictures really are in helping to improve specific aspects of learning. Is it possible

that they could sometimes be redundant or even confusing for the learners? The extent to which the content, form, and presentation mode of a picture *complements* the text it accompanies is likely to be of crucial importance in determining the instructional effectiveness of such a combination. Educators need a principle basis for allowing them to distinguish between effective and ineffective pictures, be it static or animated ones. This article, then, discusses the role of static and animated pictures that complement texts in inhancing learning and the underpinning theory that explains how people process visual and verbal information and how they can benefit from such a combination.

THE EDUCATIONAL FUNCTIONS OF PICTURES

Pictures have been used as a form of communication throughout history: pictographs on cave walls, hieroglyphics on Egyptian mausoleums, illuminations in medieval manuscripts, sketches in books, and advertisements on television (Mulcahy & Samuels, 1987). As a form of communication, pictures have been used to tell stories and describe important events. Although the development of modern written languages enabled a more sophisticated form of communication, pictures have remained an important means of recording and distributing information. The onset of the information technology age has seen a resurgence in the reliance on pictorial means of communicating, especially in the field of education.

As printing methods improved, communicating through both pictures and words became easier. Subtle relationship between text and illustrations became more realized by bookmakers, artists, and publishers. Illustrations by themselves were often considered works of art, appeared to be comprehension aids, which depicted scenes in a story or conveyed relationships between ideas (Mulcahy & Samuels, 1987).

Textbooks illustrations were rare before the eighteenth century. A notable exception is the textbook '*Orbis Sensualium Pictus*' (1810 or 1658) by Johann Amos Comenius who used illustrations to match the text with a picture clue. This publication is regarded as the first illustrated textbook. It introduces approximately 4000 words, each of them grouped together according to an area of reality (i.e., an area of knowledge, and illustrated by a wood carving). '*Orbis Sensualium Pictus*' used illustrations not merely as ornaments on the page but as teaching devices

in which picture and text were closely related in an explanatory fashion. Since the time of Comenius' picture-book, the use of illustrations has grown in importance as a central feature of educational materials and practices (Molitor, Ballstaedt, & Mandl, 1989). The role of textbook illustrations in the early age, such as '*Orbis Sensualium Pictus*' and '*The New England Primer'*, could be used as an aid for recall as well as comprehension of the text. Illustrations were especially marked as the beginning of their use as important comprehension aids by textbooks published in the early nineteenth century, such as *'The New American Primer'*. However, the comprehensibility of the picture, especially in reference to text, was not always clear. The illustrations did not always refer to the textual information on the page. Indeed the words and letter combinations placed on the same page as the illustration did not have an association whatsoever with the illustration and its caption. This could create poor 'syntactic text parallel', which according to Goldsmith (1984), refers to the 'relation of the pictorial and verbal signs'. '*The American Primer'*, though easy to review, also lacked good 'semantic text parallel' that refers to 'distinguishing features of an object' that serve to identify that object correctly (Goldsmith, 1984). This may suggest that it is not sufficient just to position text and picture close to each other. Their *contents* must be considered and carefully related to each other. However, starting from later-nineteenth century textbooks, the illustrations gradually became clearer, larger, and more directly related to the text, such that semantic and syntactic text parallels between the illustrations and the text passage improved as printing techniques improved.

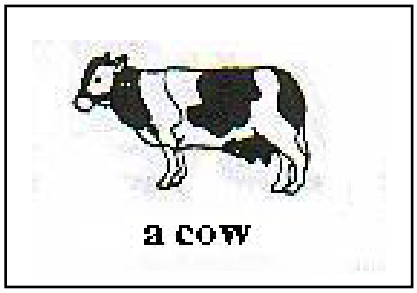
TEXT-PICTURE COMBINATION IN ESL/EFL TEACHING APPROACH

Current basic teaching resources in ESL/EFL teaching (from textbooks to computer based instruction) typically contain texts accompanied with pictures to introduce the language components, be it a word meaning, sentence meaning or the meaning of extended prose. Further, language teachers often use additional pictures to complement these resources in their teaching for various reasons, among others:

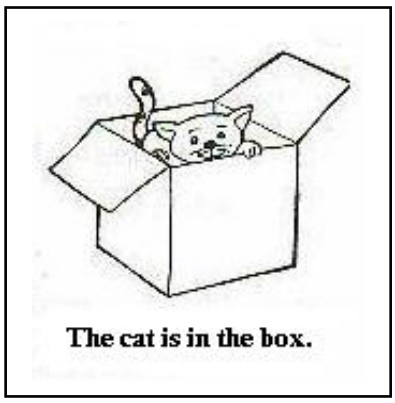
(a) to motivate learners
(b) to help facilitate learners' acquisition of language components
(c) to make the abstract concepts more concrete

(d) to clarify text content that is hard to comprehend
(e) to complement the text with information that is not available in the text

The illustrations that accompany texts are presented in several ways. The early stages of language learning tend to focus on so-called *content words* such as nouns (Washington & Naremore, 1978). In the case of nouns, the instructional materials typically portray the entity referred to by a word through the use of pictures that show the referent in isolation or with minimal context (see an illustration of a cow on the left). There is thus a simple correspondence between the word and its associated depiction.



However, students are soon moved beyond this simple matching stage and are required to deal with groups of several words that describe relationships between entities. Illustrations are also commonly used to support learning involving these larger verbal units which contain other parts of speech in addition to nouns (verbs, adjectives, prepositions, etc.). The illustration of a cat in a box (in an illustration on the left) describes a relationship between entities (a cat and a box) and is intended to complement a group of several words that conveys a prepositional relationship (*in*).



A common application of this type of depiction involves the presentation of a sentence in which the preposition is blanked out and the student is required to produce or choose the correct preposition on the basis of information given in the illustration. This type of exercise relies on the fact that a number of prepositions could be used to complete the sentence on its own in a semantically and syntactically acceptable manner (see an example below).

	The cat is _____ the box. a. on b. in c. at d. under

The incomplete sentence, '*The cat _____ the box*,' alone (without a picture) is intrinsically ambiguous until an appropriate preposition is added. The intended function of the illustration in such a case is to remove the ambiguity and constrain interpretation, so as to direct the student's choice towards a particular preposition. Theoretically, pictures could contribute towards reducing the amount of ambiguity in texts by showing missing aspects of situations represented in texts explicitly. However, this disambiguation would rely on the presence of suitable complementarity between picture and text. Gaps in the provided textual information have to be capable of being filled by the information contained in the picture.

WHY PICTURES FACILITATE KNOWLEDGE ACQUISITION

There may be several reasons why text illustrations enhance learning outcomes for illustrated text content. One possibility is offered by the research on human memory, where it is well established that memory for to-be-learned materials is improved if both a verbal and a pictorial representation can be constructed of the stimuli. For example, words are better recalled when a mental image is created of the word's denotative meaning (Paivio, 1986). Employing Paivio's (1986) dual-coding theory in the process of learning instructional materials, it can be assumed that memory for illustrated text will become richer in detail than will memory for materials consisting of text alone. As another possible explanation, it may be assumed that when similar information is provided, both verbally and pictorially more elaborate semantic processing will ensure, resulting in better comprehension and memory of illustrated text content.

Another view is that pictures in illustrated text facilitate the construction of mental models (Hegarty & Just, 1989; Mayer & Gallini,

1990; Mayer et al., 1995; Schnotz & Mikkilä, 1991). This has been explained through the assumption that verbal and pictorial explanations are processed in different cognitive subsystems which provide different support for the construction of mental models (Mayer, 1997b).

A recent explanation of the effects of pictures within explanatory texts on comprehension combines elements of both dual-coding theory and mental model theory (Schnotz, Böckheler, & Grzondziel, 1999). The Schnotz and his colleagues' model offers a more detailed account of the interplay between texts and pictures in knowledge acquisition. Based on this view, pictures which are suitable to texts are assumed to enhance knowledge acquisition. This model sets out a series of processes and sub-processes by which people are assumed to develop an understanding of verbal and pictorial information. The basic structure of this model given in Figure 1 shows its descriptive (left side) and depictive (right side) representational branches. The descriptive branch comprises the text, the mental representation of the text surface structure, and the propositional representation of the semantic content. The interaction between these representations is based on symbol processing. The depictive branch comprises the picture or diagram, the visual perception or image of the graphical display, and the internal mental model of the depicted subject matter. The interaction between these representations is based on processes of analog structure mapping.

During the process of comprehending a text, the reader constructs a mental representation of the text surface structure, generates a propositional representation of the semantic content and from this so-called text basis, constructs a mental model of the described subject matter (Schnotz et al., 1999). The construction of a mental model during text comprehension implies a transition from a descriptive to a depictive representation. This transition is based on different, but *complementary,* principles of representation. In comprehension of pictures, the observer creates a visual mental representation or visual image of the graphic display with the help of preattentive perceptual processes as well as a mental model and a propositional representation of the depicted subject matter. The propositional representations and mental models interact continuously both in comprehension of texts and in comprehension of pictures via an interplay of model construction and model inspection.

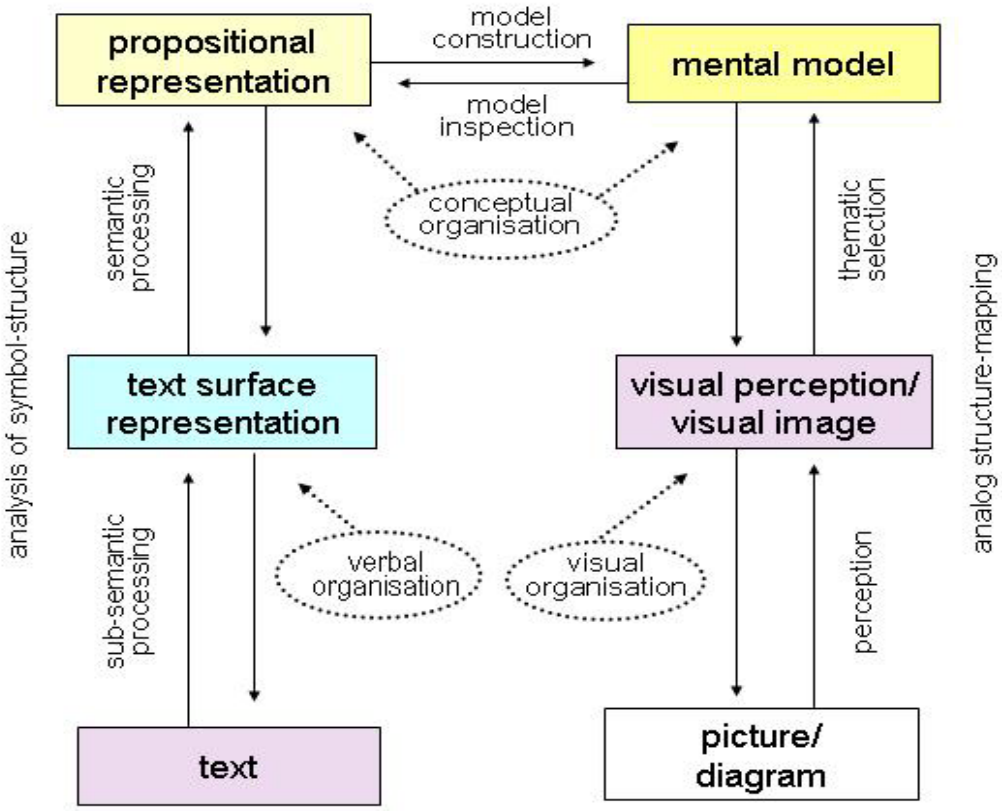


Figure 1. Schnotz, Böckheler and Grzondziel model of knowledge acquisition from text and pictures (1999).

The model suggests that pictures can function to remove potential ambiguity in the verbal (textual) presentation of subject matter by providing additional information. However, the pictorial information needs to be *complementary* to the textual information in order to disambiguate the verbal presentation. 'Complementarity' refers to the condition where both sources of information (text and picture) must be processed in order to reveal the entire meaning of text-picture/diagram combination. That is, textual information has gaps which have to be filled by the information contained in the picture, and vice versa (Molitor et al., 1989). According to Schnotz's and his associates' (1999) model, text comprehension and picture comprehension provide different routes for mental model construction (supported by background knowledge) which implies that one route can replace the other to some extent. This model provides a framework to explain individual differences in multimedia learning. Various studies have shown that learners with high background knowledge may not profit very much from pictures in texts, whereas

learners with low background knowledge may benefit relatively more (Schnotz, 2001). Obviously the high background knowledge allows mental model construction from the text also without pictorial support, whereas such external support is required for learners with low background knowledge.

In using prepositions for sentence completion, such as '*The box is floating* _____ *the beach*,' learners may find it difficult to decide which preposition is the most suitable one because a number of prepositions could be used to complete the sentence in a semantically and syntactically acceptable manner. In this situation, Schnotz's and his associates' (1999) model may suggest that unless the learners are able to generate the required mental model of the referent situation, they will not be able to choose the preposition intended to complete the sentence. However, the generation of the intended mental model would not only involve the sentence (as the sentence is incomplete), but also involve its accompanying picture and the learner's background knowledge. In relation to the accompanying pictures, a picture that is complementary to the text information may remove the ambiguity, constrain possible interpretations (Ainsworth, 1999), and direct the learner's choice towards a particular preposition. However, this relies upon the picture sufficiently disambiguating the sentence. It basically depends on the design features of the depiction. Proper picture designs are likely to specify prepositions sufficiently for there to be no problematic ambiguity in the depiction. With regard to the learners' background knowledge, this factor may involve their pictorial literacy and its contents.

WEAKNESSES OF STATIC PICTURES

Static pictures can be used to display static aspects of the situation they represent but can also include special features that allow them to depict dynamic processes. For the latter purpose, components such as shading, dotted images, or arrows must be used to symbolize the situation's dynamics. These components function as external cues that can provide an *indirect* external representation of the relevant dynamic information. In many cases, the use of these pictorial cueing devices or the use of series of frames may be sufficient to successfully support the understanding of dynamic aspects of a situation (see Schnotz & Lowe, 2002). However, by their very nature static illustrations are incapable of

representing temporal relationships in the same direct analog fashion that they can for visuo-spatial information (Lowe, 1999). Static instructional illustrations represent the dynamic aspects of a situation in an implicit, partial manner rather than in a fully explicit fashion. An external representation of subject matter that involves temporal change that provides scanty information about these dynamics is likely to be problematic for learners, especially if they lack background knowledge about the depicted content (Lowe, 1999). For such learners, animated pictures may be more effective than static depictions because they can provide a *direct* external representation of situational dynamics.

THE ROLE OF ANIMATION IN ENHANCING LEARNING

Animation can be used to make change processes explicit to the learner (Lowe, 1999). It brings three attributes to an instructional setting: (a) visualization, (b) motion, and (c) trajectory (that refers to the direction of the path of travel of an animated object) (Klein, 1987). In animation presentations, animation can be used with or without accompanying text to demonstrate or elaborate a lesson fact, concept, rule, or procedure (Rieber, 1990). Generally animation has been used in instruction to fulfil or assist one of several functions. Park (1998), for example, claims that animation can be an important instructional tool, serving functions such as (a) attracting and directing learner attention, (b) representing dynamic domains, and (c) explaining complex system events (e.g., structural and functional relationships among system components). However, Rieber (1994) observes that "animation is most commonly used for cosmetic purposes, with the intent of impressing rather than teaching (p. 145)."

Several studies that have investigated the effects of animations on learning resulted in inconsistent findings, not only in terms of whether or not animation is advantageous to learning, but also in terms of the specific factors that may influence those cognitive benefits or disadvantages (See Dahlqvist, Ramberg, & Waern, 1999; Price, 2002). Some research has shown animation to be advantageous in some learning situations, others have not (Tversky & Morrison, 2002).

Price (2002) suggested that the effectiveness of animations for helping learners understand dynamic systems is influenced by the extent to which the portrayal makes those dynamics visually explicit. However, learners are required not only to 'see' the dynamics, but also to interpret

the meaning behind the changes that are occurring in the presentation, and to 'integrate' all of these pieces of information into a coherent understanding of the system as a whole. This is to say that the use of animated illustrations to facilitate understanding of a dynamic process is not merely a matter of providing visually explicit information. There is more for the learner to achieve in understanding from this kind of representation than 'seeing' the depicted dynamics. It is likely that, as with static illustrations, design features can be crucial to the effectiveness of animated illustrations. This issue is discussed in the next section.

The design of animations involves manipulation of various dynamic characteristics. Animation has, among others, 'translation' characteristics that involves "the movement of whole entities from one location to another and can be perceived with respect to the border of the animation or other material within the animated display" (Lowe, 2002, p. 3). The 'translation' information shown indirectly in static illustrations can be shown in a direct, analogue way by animation. So animation can replace the arrows/dotted images commonly used to represent the dynamics of a situation depicted through static pictures.

1. The Role of Design Features In Learning from Animations

Mayer and Anderson's (1991; 1992) work on the use of verbal narration or text in conjunction with animation, showed that understanding concepts using animation was significantly improved if verbal explanation ran concurrently with the animation. "Students learn best when words and pictures of an explanation are presented contiguously in time and space" (Mayer & Anderson, 1992, p. 450). This 'concurrency' of the text and animation is a 'design factor'; however, it is design of the *combination*, not the internal characteristics of the animation itself. Mayer's research does not go into detail about the way the animation portrays entities and relations referred to in the text.

The representational design of the animation has also been shown to affect whether animation is beneficial or not to understanding. Kaiser et al. (1992) completed a series of studies investigating the use of animation on people's perception and understanding of mechanics. They found that animation was advantageous when the representation showed unidimensional dynamics (only one dynamic event) as opposed to multidimensional dynamics. The findings may suggest that the design feature of complexity of the dynamic portrayal is likely to influence animation's effectiveness.

2. Strengths and Weaknesses of Animated Pictures

Animations have become popular in many computer-based instructional products. In comparison with static illustrations, animations have the potential to be especially beneficial for instruction presenting dynamic contents because animated pictures can show information about two important visual attributes: motion and trajectory. They can provide information about the motion of an object, if it is moving, if the motion is changing, and how it is moving (path, patterns, etcetera). They can also show information about which way the object is moving (Rieber, 1996).

Animated pictures can provide possible cognitive processing benefits circumventing problems associated with a lack of background knowledge about the dynamics of unfamiliar subject matter that may occur with static representations (Lowe, 1999). By explicitly portraying the temporal changes (rather than relying on the learner to infer dynamics), an animation could supply the dynamic information necessary for a learner to construct a high quality mental model of the depicted situation. Another possible benefit could be that "an animated portrayal is structurally and functionally closer to a mental model than a static depiction so that its dynamic information is more readily taken up and incorporated into a mental model" (Lowe 1999, p. 227).

Comparing both animated and static types of illustrations, numerous similarities have been found concerning the representation of objects. However, animated illustrations seem to be superior for the visualization of spatial aspects and dynamic processes, whereas in static illustrations, static indicators such as shading or arrows are used to symbolize this information. Dynamic illustrations offer a complete model for generating a mental representation of motion so as to reduce the level of abstraction of temporal ideas and accordingly they should support deeper understanding than static illustrations do (Park & Hopkins, 1993). In other words, animation does not only provide direct external representation of a situation's dynamic but also make the spatial relation less dominant over the temporal relation.

The essential instructional characteristics that distinguish dynamic from static illustrations is their capacity to depict temporal change directly. Animated illustrations, for instance, convey the visuo-spatial structure of static pictures information and also display the transformation of the structure over time. This can be seen as an aid to create dynamic, runable mental models of the information presented (Lowe, 2002; Schnotz & Grzondziel, 1996).

Further, animations are generally assumed to be instructionally superior to static depictions. In particular, it is possible that animations could be preferred over static depictions in preposition learning because a preposition usually indicates, among others, the spatial and temporal relationships of its object to the rest of the sentence. These relationships can be shown more clearly via animations than static depictions because, according to Lowe (1999) static depictions are limited to spatial information whereas animations convey information about both spatial structures and temporal structures by visualising processes and envisioning the dynamic characteristics of a subject matter.

Animations could also be disadvantageous. Although animations are generally assumed to be instructionally superior to static depictions, Lowe's (1999) research indicates that in some cases animations may not be superior to static depictions because animations involve the processing demands that can have negative effects on learning. When learning with dynamic illustrations, learners are likely to face similar or even more challenging problems (Lowe, 1999). The transitory nature of dynamic visuals confronts learners with higher levels of cognitive load than would be expected for static visuals. On the other hand, the apparent simplicity of the dynamic information presented may influence the learners to adopt a lower amount of invested mental effort and volitional attention (Rieber, 1989). Schnotz (2001) also claimed that animations were processed only superficially, and learners acquired misconceptions about the subject matter. As a result, the use of animated pictures also resulted in lower performance than the use of static pictures as indicated by a number of previous studies.

Further, it is possible that the potential support of animations may be useless because individuals have less control of their processing in learning from animations and therefore have restricted opportunities to use appropriate learning strategies (Schnotz & Bannert, 2002). The use of animation on diagrams results in an unmanageable increase of perceptually available information, especially where multidimensional dynamics are involved (e.g., Kaiser et al., 1992). Several studies comparing the use of animated and static representations in varying domains also show no consistent evidence of improved learner understanding, suggesting that provision of a moving image may not necessarily facilitate overall conceptual understanding.

Although animation may depict dynamic aspects of situations more visually explicit, the form of animation itself may detract from the potential benefits of this explicitness. Stenning (1998), for example, proposes that animation may result in complexity for the learner and may be a consequence of 'transient form' of animation. 'Transient form' of animation may enhance the problem of memory load. In addition, learners are unable to reaccess pieces of information from the animation as they are no longer perceptually available. Learners therefore have no control over what information is viewed, or for how long, as the information is continuously passing by.

3. Animations and Subjects' Background Knowledge in Learning from Animations

In learning with animated illustrations or diagrams the extent of background knowledge of the depicted contents and expertise at reading illustrations would cognitively guide the learner in their processing of the information. Lowe's (1996) study, for instance, investigating differences between novice and experts of meteorology using animated representations of weather maps showed that lack of background knowledge appeared to be a serious impediment to novices interpretation of static displays because they did not know the dynamics.

Lowe (1999) argues that learners with comparatively little domain knowledge perceive and remember mostly those characteristics of the display that are perceptually salient (i.e., components of the animation that change either substantially more than their surroundings or substantially less than their surroundings). The instructional implication can only be that animations need to be very carefully designed when presenting them to novices as a learning resource. In particular, animation designers have to ensure that the visually salient features of an animation are as much as possible aligned with the conceptually important components.

Benefits of using animation were shown to be evident for particular subject groups, for example Hays (1996) found animation improved performance for lower spatial ability individuals, but this was only apparent in contexts where understanding of a process involved dynamic or spatial processes. Rieber (1990) found animation improved performance for children learning about Newton's laws of motion, but not for adults.

CONCLUSION

This article provides a discussion of the roles of text-picture combination in enhancing knowledge acquisition and the underlying theory that explains how people can benefit from such a combination. The literature indicates the potential benefit of text-picture combination in a subject matter although, it is noted, poorly designed pictures can interfere with learning. Careful designs of a picture (be it static or animated) are essential for the effectiveness of pictures as a complement to text. It is the picture designs that are closely related to the construction of mental models. Proper picture designs may contribute much to the construction of an intended mental model of the depicted situation.

REFERENCES

Ainsworth, S. 1999. The functions of multiple representations. *Computers & Education, 33*, 131-152.

Bock, M. 1978. Levels of processing of normal and ambiguous sentences in different contexts. *Psychological Research, 40*, 37-51.

Braun, C. 1969. Interest-loading and modality effects on textual response acquisition. *Reading Research Quarterly, 4*, 428-444.

Dahlqvist, Ramberg, R., & Waern, Y. 1999. *The effects of different presentation formats on learning*. Retrieved January 26, 2003, from: http://www.dsv.su.se/~patricd/Publications/EARLI-99.PDF

Dwyer, F. M. 1970. Exploratory studies in the effectiveness of visual illustrations. *AV Communication Review, 18 (3)*, 235-249.

Vernon, M. D. (1953). The value of pictorial illustration. *British Journal of Educational Psychology, 23*, 180-187.

Glenberg, A. M., & Langston, W. E. 1992. Comprehension of illustrated text: pictures help to build mental models. *Journal of Memory and Language, 31*, 129-151.

Goldsmith, E. 1984. *Research into illustration: an approach and a review*. Cambridge, England: Cambridge University Press.

Gyselinck, V., & Tardieu, H. 1994. Illustrations, mental models, and comprehension of instructional text. In W. Schnotz & R. W. Kulhavy (Eds.),

Comprehension of Graphics (pp. 139-151). North-Holland: Elsevier Science B. V.

Hannus, M., & Hyönä, J. 1999. Utilization of illustrations during learning of science textbook passages among low-and high-ability children. *Contemporary Educational Psychology, 24*, 95-123.

Harber, J. N. 1983. The effects of illustrations on the reading performance of learning disabled and normal children. *Learning Disability Quarterly, 3*, 60-70.

Hays. 1996. Spatial abilities and the effects of computer animation on short-term and long-term comprehension. *Journal of Educational Computing Research*, *14*, 139-155.

Hegarty, M., & Just, M. A. 1989. Understanding machines from text and diagrams. In H. Mandl & J. R. Levin (Eds.), *Knowledge Acquisition from Pictures* (pp. 171-194). Amsterdam: Elsevier Science Publishers B. V.

Johnson-Laird, P. N. 1983. *Mental models. Towards: a cognitive science of language*. Cambridge, England: Cambridge University Press.

Kaiser, M., Proffitt, D., Whelan, S., & Hecht, H. 1992. Influence of animation on dynamical judgement. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 669-690.

Klein, D. 1987. Conditions affecting the effectiveness of animated and non-animated displays in computer-based instruction. Paper presented at the annual meeting of the Association for the Development of Computer-Based Instructional Systems. Oakland, C.A.

Koran, M. L., & Koran, J. J. 1980. Interaction of learner characteristics with pictorial adjuncts in learning from science text. *Journal of Research in Science Teaching, 17*, 477-483.

Lowe, R. K. 1999. Extracting information from an animation during complex visual learning. *European Journal of Psychology of Education, 14 (2)*, 225-244.

_____ . 2002. Animation and learning: selective processing of information in dynamic graphics. *Learning and Instruction,* Article in press, 1-20.

Mayer, R. E. 1989. Systematic thinking fostered by illustrations in scientific text. *Journal of Educational Psychology, 81 (2),* 240-246.

_____ . 1993. Comprehension of graphics in text: an overview. *Learning and Instruction, 3*, 239-245.

_____. 1997. Multimedia learning: Are we asking the right questions? *Educational Psychologist, 32 (1)*, 1-19.

Mayer, R. E., & Anderson, R. B. 1991. Animations need narrations: an experimental test of a dual-coding hypothesis. *Journal of Educational Psychology, 83 (4)*, 484-490.

_____. 1992. The instructive animation: helping students build connections between words and pictures in multimedia learning. *Journal of Educational Psychology, 84 (4)*, 444-452.

Mayer, R. E., & Gallini, J. K. 1990. When is an illustration worth ten thousand words? *Journal of Educational Psychology, 82 (4)*, 715-726.

Mayer, R. E., Steinhoff, K., Bower, G., & Mars, R. 1995. A generative theory of textbook design: using annotated illustrations to foster meaningful learning of science text. *Educational Technology Research and Development, 43*, 31-44.

Molitor, S., Ballstaedt, S. -P., & Mandl, H. 1989. Problems in knowledge acquisition from text and pictures. In H. Mandl & J. R. Levin (Eds.), *Knowledge Acquisition from Text and Pictures, 58* (pp. 3-35). North-Holland: Elsevier Science Publishers B.V.

Mulcahy, P., & Samuels, S. J. 1987. Three hundred years of illustrations in American textbooks. In H. A. Houghton & D. M. Willows (Eds.), *The Psychology of Illustration, 2* (pp. 1-52). New York: Springer-Verlag.

Paivio, A. 1986. *Mental Representations*. New York: Oxford University Press.

Park, O. 1998. Visual displays and contextual presentations in computer-based instruction. *Educational Technology Research and Development, 46 (3)*, 37-50.

Park, O., & Hopkins, R. 1993. Instructional conditions for using dynamic visual displays: a review. *Instructional Science, 21*, 427-449.

Peeck, J. 1993. Increasing picture effects in learning from illustrated text. *Learning and Instruction, 3*, 227-238.

Price, S. J. 2002. *Diagram representation: the cognitive basis for understanding animation in education.* Unpublished Ph.D. Thesis, University of Sussex, Brighton.

Reid, D. J., & Beveridge, M. 1986. Effects of text illustration on children's learning of a school science topic. *British Journal of Educational Psychology, 56*, 294-303.

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 (4)*, 431-444.

_____. 1994. *Computers, Graphics, & Learning*. Madison: Brown & Benchmark.

_____. 1996. Animation as feedback in a computer-based simulation: representation matters. *Educational Technology Research and Development 44 (1)*, 5-22.

Rieber, L. P., Boyce, M. J., & Assad, C. 1990. The effects of computer animation on adult learning and retrieval tasks. *Journal of Computer-Based Instruction, 17*, 46-52.

Rohwer, W. D., Jr., & Matz, R. D. 1975. Improving aural comprehension in white and black children: picture versus print. *Journal of Experimental Child Psychology, 19*, 23-36.

Samuels, S. J. 1967. Attentional process in reading: the effect of pictures on the acquisition of reading responses. *Journal of Educational Psychology, 58 (6),* 337-342.

Schnotz, W. 2001. *Educational promises of multimedia learning from a cognitive perspective.* Paper Presented at the 9th European Conference on Research on Learning and Instruction (EARLI), Fribourg/Switzerland.

Schnotz, W., & Bannert, M. 2002. Construction and interference in learning from multiple representation. *Learning and Instruction,* Article in press, 1-15.

_____. 2003. Construction and interference in learning from multiple representation. *Learning and Instruction, 13*, 141-156.

Schnotz, W., & Lowe, R. K. 2002. Introduction: external and internal representations in multimedia learning. *Learning and Instruction,* Article in press, 1-7.

Schnotz, W., & Mikkilä, M. 1991. *Symbolic and analog representations in understanding the functioning of a microcomputer*. Tubingen: Deutsches Institut fur Fernstudien an der Universitat Tubingen.

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

Schnotz, W., Picard, E., & Hron, A. 1993. How do successful and unsuccessful learners use text and graphics. *Learning and Instruction, 3*, 181-199.

Stenning, K. 1998. Distinguishing semantics from processing explanations of usability of representations: applying expressiveness analysis to animation. In J. Lee (Ed.), *Intelligence and Multimodality in Multimedia Interfaces: Research and Applications.* Menlo Park, California*:* AAAI Press.

Tversky, B., & Morrison, J. B. 2002. Animation: can it facilitate? *International Journal of Human-Computer Studies, 57*, 247-262.

Vernon, M. D. 1954. The instruction of children by pictorial illustration. *British Journal of Educational Psychology, 24*, 171-179.

Washington, D. S., & Naremore, R. C. 1978. Children's use of spatial prepositions in two-and three-dimensional tasks. *Journal of Speech and Hearing Research, 21*, 151-165.