Dimensionality and its Effect on Retention and Visual Scanning

Farough Abed

Abstract: In a study of two-dimensional and three-dimensional illustrations, Abed (1991) found that scanning patterns varied significantly for the two Illustration types. The present study uses the two illustration types as components in illustrated texts to look at their effects on retention. Eighth graders read/viewed an illustrated text while their eye movements were recorded, and were administered a multiple-choice retention test im mediately after. It was found that scanning behaviors were different for the two treatment groups, with the 3D group spending more time on the illustration, less time on the text, and interrupting reading more often than the 2D Illustration group. The results support Abed (199') as well as Dwyer 's (1970) conclusion that realism in illustrations is not necessarily facilitating; in the present investigation it proved to be distracting.

Resume: Dans une etude effectuee sur des illustrations bidimensionnelles et tridimensionnelles, Abed (1991) a decouvert que les aires de balayage variaient considerablement selon le type d'illustration. La presente etude integre ces deux types d'illustrationsdans des textesecrits en vued'evaluer leur incidence sur letaux de retention. Des eleves de huitiemeanneesont appeles a llreou a visionner un texte illustre cependant qu'on enregistre le mouvement de leurs yeux. Aussitot apres, on leur fait passer un examen a choix multiple en vue de mesurer ce qu'ils ont retenu. L'etude a revele que les aires balayees differaient d'un groupe de sujets a I'autre, celui des 3D s'attardant davantage sur ('Illustration, consacrant mains de temps au texte et interrompant plus souvent sa lecture que le groupe des 2D. Ces conclusions vlennent appuyer les resultats des travaux de Abed (1991) et de Dwyer (1970), selon lesquels le realisme de I'illustration n'est pas necessairement un element facilitateur. A vrai dire, la presente etude indique que c'est plutot un facteur distrayant.

In an experiment on the effects of dimensionality on eye movement, Abed (1991) compared scanning strategies used for three-dimensional and two-dimensional visuals. The three-dimensional visual stimuli consisted of color representational drawings with two components: a flat background picture plus a picture which folded out to present a three-dimensional (3D) model to the learner. The two-dimensional (2D) stimuli were photographs of the 3D stimuli. The results of the study showed significant differences between scanning behaviors associated with the two types of visuals. While the 3D treatment group fixated more on the foreground area than the 2D treatment group, the reverse situation occurred for the background area. Similarly, the left-side preference generally displayed in eye movement studies (and seen in the 2D treatment group) was disrupted by the presence of three-dimensional stimuli, so that subjects viewing 3D visuals spent roughly equal amounts of time viewing both left and right sides of the visuals. The results of this study illustrate that dimensionality influences viewing patterns. The purpose of the present study is to pursue this finding further in the context of learning; specifically, will two-dimensional and three-dimensional illustrated texts result in varying levels of retention as well as varying eye movement behaviors? Peeck (1987) has suggested the use of eye movement recordings to determine how and when viewers use illustrated text. By gathering this data along with retention test data, the investigator is able to determine the interaction between subjects' attention to specific areas and their retention of textual and pictorial information. Some eye movement data is available in connection with textbook illustrations.

Fleming (1984) recorded the eye movements of graduate students as they studied illustrated texts. A number of variables were considered, including page layout and complexity of material, as well as the learner characteristics of sex, cognitive style and prior knowledge of material. Among'other findings, Fleming reported that more transitions (from text to illustration) were made while studying complex rather than simple material, the complex material being from a scientific research journal and the simple material from an 8th grade text. That complex stimuli attract more viewer attention (eye fixations) than simple stimuli has been found by many researchers, including Faw and Nunnally (1967,1968), and Mackworth and Morandi (1967).

In a study by Flagg, Weaver, Fenton, Gelatt, and Pray (1981), third and fifth graders' eye movements were recorded while they read passages with or without illustrations, and they were subsequently tested for recall. Duration of fixations on the text varied little for the three picture conditions (no picture, picture before text, and picture with text). In the picture with text treatment, the children spent an average of 5.6% of their total viewing time fixating or scanning the illustration. One of three approaches was used: examination of the picture before and after reading the text, examination of the picture either before or after reading the text, or interruption of reading to examine the picture. Half of the children used this last approach, and of these children half interrupted reading more than once. A few children did not look at the picture at all. Further, children who attended more to the illustration had significantly better recall of details in the text.

It is apparent, then, that different illustrations or illustration/text units can yield different eye movement patterns. Can they also influence learning in different ways? Much of the research points to the facilitating effects that illustrations can have on comprehension and retention (i.e., Bransford and Johnson, 1972;Duchastel, 1981; Peeck, 1974). But it is not certain that just any type of illustration would be useful in a given situation. As Willows (1980) pointed out, researchers often assume that "a picture is a picture is a picture." In fact, pictures vary in numerous aspects, including color, size, placement, density of information and realism vs. symbolism. These variables can be combined in any number of ways to form an illustration that may enhance textual information or detract from it.

Three-dimensionality is perhaps most closely linked to realism, which has been described by Dwyer (1978) as "the amount of stimuli available to convey information to the student." Three-dimensionality in an illustration (i.e., a fold-out model) would add the real-world perspective and depth lacking in an illustration confined to the limitations of a two-dimensional surface. The realism theories put forth by Morris (1946), Dale (1946), Carpenter (1953) and others suggest that learning will be facilitated by increasing realism. Accordingly, various types of visual stimuli will enhance learning to varying degrees, with realistic photographs being the most facilitating, followed by photographs of models, detailed and shaded drawings and simple line drawings. In each case color visuals would be more realistic and facilitating than black and white. By extension of this theory, a three-dimensional illustration would be somewhere on the upper end of the continuum.

After extensive study on the subject of realism, Dwyer (1970) summarized his research comparing various types of visuals designed to teach the anatomy and physiology of the human heart, and concluded that adding realistic cues led to increased learning only under certain conditions. His visuals included simple line drawings, detailed shaded drawings, photographs of heart models, and photographs of heart specimens, all presented in color and in black and white. Of particular interest here are three findings. 1) Highly realistic visuals tended to increase learning when study time was self-paced, but not when presentation times were fixed. Dwyer speculated that the fixed viewing time did not allow students to absorb and interact with all the information provided in such complex visuals. 2) Extra details in realistic visuals sometimes served as distractors rather than enhancers, causing students to miss more important visual or textual cues. 3) Different types of visuals were more or less facilitative for different educational objectives. If one objective of the illustration is to be aesthetically pleasing and thereby maintain interest in the text, this does not necessarily imply that other cognitive objectives will be achieved as well. Parkhurst (1982) also reached this last conclusion after studying the interaction between media presentation method, visual realism, and level of reading comprehension. The visual realism variable included four possibilities: no visuals, line drawings, detailed shaded drawings, and realistic pictures of the object. Test scores increased along with the degree of realism for subjects with high comprehension levels. For those with low comprehension levels, test scores decreased as visual realism increased.

These studies necessarily objectified pictorial realism as a factor made up of certain components. In fact there are numerous components to this principle, some more qualitative than others. Kawabata (1986) lists texture gradients, perspective, shadows, and intensity gradients as some of the various cues which contribute to the perception of realism or three-dimensionality in a two-dimensional plane. Haber (1980) discusses phenomena such as the relative size of objects in the picture, convergence of visual edges toward a distant vanishing point, and lighting as signals to the viewer that the picture is intended to convey three-dimensionality. For actual three-dimensional illustrations the realistic quality stems from several sources. First, the fact that the illustration is an actual paper model which reveals visual information in a three-dimensional mode adds the depth lacking in a conventional two-dimensional format. Second, the addition of any or all other variables such as color, detail, and Kawabata's and Habeas cues would serve to increase the realistic quality of the illustration.

The present study compares the effects of two-dimensional and three-dimensional illustrated texts on eye movement strategies and on retention of information. Because of the tendency of three-dimensional illustrations and other complex visuals to alter viewing patterns (Abed, 1991; Fleming, 1984), it was hypothesized that fixation patterns would differ for the two types of visuals and that the three-dimensional illustration would attract more attention than the two-dimensional illustration. Taking into consideration the mixed results of realism studies and the fact that realistic illustrations sometimes act as distractors, it was further hypothesized that three-dimensional illustrations would fall into this category, and therefore would lead to lower retention test scores than two-dimensional illustrations.

METHODOLOGY

Subjects

Twenty eighth graders from a public middle school were selected for participation in this study. All had average or above average reading skills (indicated by class placement and school records) and normal or corrected vision. Students were randomly assigned either text with three-dimensional (3D) illustrations or text with two-dimensional (2D) illustrations, so that 10 students saw each. The three-dimensional illustrations represented a greater degree of complexity and realism than the two-dimensional images.

Materials

Each subject saw three 11" x 14" stimuli covering the subjects of Cro-Magnon homes, art, and technology. Each stimulus contained a column of text on the extreme left-hand side of the page with the remainder of the page (about 80%) covered by an image depicting some aspect of the subject matter. Several librarians rated the three stimuli as being appropriate for fifth or sixth grades, which ensured that difficulty in text comprehension would not be a confounding factor in the experiment. Each stimulus contained separate information in the text (T) and the picture (P), as well as information contained in both (P+T). Students were screened for prior knowledge of the subject matter but none had any.

To understand the difference between the 2D and 3D visuals, it is important to make a distinction between real and perceived three-dimensionality. Perceived three-dimensionality is potentially available in any 2D illustration, and is characterized by the cues discussed above (see Haber, 1980 for an in-depth discussion of this concept). The objects in the illustration give it height and width, but since it is a flat illustration it is lacking the real depth (physical distance between foreground and background) available in the three-dimensional model. Such cues as shadows, source of light, and relative size of objects give the perception of three-dimensionality. Real three-dimensionality is found in a three-dimensional model and is characterized by height, width and depth. In this case depth is not merely perceived, but achieved by physical distance between foreground and background objects. For example, a two-dimensional illustration might depict a basketball in the foreground and a hoop in the background. The ball is slightly larger than the hoop to provide the viewer with the illusion of depth since both objects are illustrated on a flat surface. In the three-dimensional model the basketball is brought forward by means of a cardboard strip to provide the viewer with realistic rather than perceived depth. In other words, the ball is actually closer to the viewer than the hoop. All other cues are constant in the two illustrations; that is, the size of the ball, shadow, perspective, etc. all remain the same. The sole difference is the distance between the foreground and background.

For the 2D stimuli in the present study the perception of three-dimensionality was obtained by adhering to many of the cues listed earlier: the illustrations were fully detailed, realistic renderings of the subject matter, including such cues as color, shadow, texture, perspective, and relative size of objects. Foreground and background were not actually separated by physical distance, and the viewer relied on the aforementioned cues for the perception of three-dimensionality. For the 3D illustrations the same renderings were used, giving the same perception of three-dimensionality as in the 2D illustrations with the addition of depth. In other words, the foreground and background were physically separated by raising the foreground with a piece of cardboard. As an example, one of the illustrations depicted a group of Cro-Magnon people using spears to hunt a wooly mammoth. The foreground shows the wooly mammoth's head facing the viewer. Two hunters are standing before the animal with their backs to the viewer. The background depicts other hunters and the general terrain. In the 2D version the size and placement of the mammoth and the hunters show their relationship in space. In the 3D version the mammoth and the two hunters in front are raised to provide proximity to the viewer, adding real depth. All other cues are constant in the two illustrations.

An NAC Eye Movement Recorder Mark IV was used to collect the eye movement data. The camera was connected to a VHS video tape recorder and all data were recorded on a half-inch video cassette for later analysis.

The multiple choice test consisted of 45 randomized items (21 T, 17 P, and 7 P+T) covering all three stimuli. The items were tested for reliability (alpha = 0.71) using 15 additional students who saw three-dimensional illustrations. The mean score for this group (25.6) was compared to that of the three-dimensional treatment group (25.8) to check for any effect that the eye movement equipment might have on retention performance, but none was evident. A sampling of test questions is provided in *Appendix A.*

Procedure. Students were tested individually in a small room provided by the school. Each student was seated at a self-determined comfortable reading distance from the easel holding the stimuli. Subjects were not allowed to turn or manipulate the stimuli in any way. For purposes of this investigation the frontal view was of primary interest, and multiple perspectives (i.e., the side or back of the 3D model) did not matter. The experimenter explained the apparatus while fitting it on the subject, and then used a target board to calibrate the equipment. The apparatus did not restrict head movement. Subjects were instructed to read silently at their own pace and to indicate to the experimenter when the stimulus should be changed. Once the reading was completed, the apparatus was removed. The experimenter instructed the students to think about both the text and the illustrations, and then the test was administered. Upon completion of the test, students were asked to refrain from discussing the experiment with others.

The eye movement data was used to compute three scores for each stimulus: 1) amount of time spent fixating the visual, 2) amount of time spent fixating the text, and 3) number of interruptions during reading of the text. The total amount of time spent fixating all three stimuli (text and illustration) was also determined. A counter (minutes, seconds, frames) was used to make the time calculations in seconds (accurate to the nearest half-second). Interruptions were defined as transitions from the text to the visual and back again. Returning to the text was deemed important in scoring reading interruptions since many subjects ended a page by fixating the visual. The retention tests were used to compute a total score, as well as separate scores for picture items, text items and picture + text items.

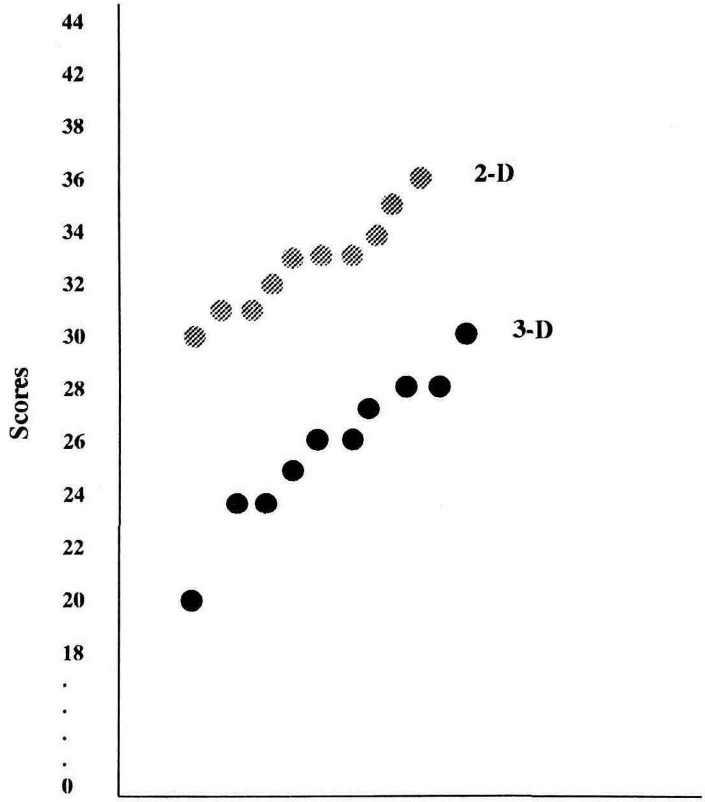
RESULTS

The analysis of the data served to answer three specific questions. First, did the dimensionality variable have an effect on the retention test scores? Second, were the recorded eye movement behaviors affected by dimensionality? Third, if dimensionality did have an effect on both test scores and eye movement, were the latter two variables related?

The retention test scores were significantly different for the 2D and 3D illustration groups (t = 6.604, df = 18, $p<.001$), with the 2D group scoring higher. Even though study time was self-paced, as Dwyer (1970) recommended for realistic illustrations, the greater degree of realism in the 3D illustrations did not facilitate learning. Individual scores graphed in Figure 1 clearly indicate that these scores represent two different sets.

Two-tailed t-tests were used to determine whether the dimensionality factor had any effect on the type of question remembered (P, T, P+T). Table 1 gives means and standard deviations. The 2D group scored significantly higher on both T items (t = 5.12, df = 18, $p<.0005$) and P+T items (t = 4.02, df = 18, $p<.001$). This

Figure 1.
Total Scores for Recall Tests



result was different from that of Flagg et al. (1981), who found that subjects attending more to the illustration had better text recall. For P items the effect was almost significant (t = 2.01, df = 18, p<.059) with the 2D group again scoring higher.

The data suggest that dimensionality also had an effect on the recorded eye movement behaviors. Two-tailed t-tests were utilized to look at all three stimuli together. The results were significant for all three eye movement measures: illustration time (t = 6.547, df = 58, p<.0001); text time (t = 2.22, df = 58, p<.0304); and number of interruptions while reading (t = 6.438, df = 58, p<.0001).

The total amount of reading/viewing time for the combined stimuli varied little among subjects, ranging from 4 min. 13.5 sec. to 5 min. 13.5 sec. The mean reading/viewing times were 4 min. 43.7 sec. for the 2D group and 4 min. 45.4 sec. for the 3D group. Similarly, the mean reading/viewing times per stimulus varied little between groups. The reading/viewing patterns, however, differed considerably for the two groups in terms of time spent on text and illustration and the number of times reading was interrupted to view the illustration. For instance, on stimulus #1 the 2D group averaged 9.75 sec. of illustration time and 73.35 sec. of text time. The 3D group averaged 15.9 sec. of illustration time and 66.6 sec. of text time. This trend was similar for all stimuli, with the 3D group spending more time on the visual and slightly less time on the text than the 2D group. For stimuli #2 and #3 the difference in visual time was even more pronounced, with the 3D group spending more than twice as much time on the visual as the 2D group. Additionally, the mean number of interruptions (for all stimuli combined) for the 2D group was 0.4, while for the 3D group it was 1.57. This finding is similar to Fleming's (1984) results showing that complex material led to more frequent interruptions in reading, although his stimulus complexity occurred primarily in the text rather than the illustration.

TABLE 1
Mean Scores and Standard Deviations for Retention Test

	Picture (P) n-17items		Text (T) n=21 items		Picture + Text (P+T) n=7 items		Total n=45 items	
	2-D	3-D	2-D	3-D	2-D	3-D	2-D	3-D
$\bar{X}$	12.0	10.3	15.8	12.0	5.0	3.5	32.8	25.8
S.D.	0.943	2.497	1.619	1.700	0.667	0.972	1.874	2.781

Having seen that dimensionality had an effect on both retention scores and eye movement behaviors, it was left to determine if there was a relationship between test scores and any of the following: time spent on the illustration, time spent on the text, and/or number of interruptions. All correlations were low, the highest being an r value of -.442 for the relation between text time and test score. Thus it can be concluded that the eye movement behaviors studied had little association with the retention test scores.

DISCUSSION

The data above indicate once again that dimensionality has an effect on eye movement behaviors, as Abed (1991) showed. Fixation patterns did indeed vary for the 2D and 3D illustrations, with the 3D illustration attracting more attention. Retention was also influenced by dimensionality. However, retention scores and eye movement behaviors were not found to be related to each other.

Subjects in the 3D group spent more time on the visual, less on the text, and interrupted their reading almost 4 times as often as those in the 2D group, and their retention scores were significantly lower. Like the children in the Flagg et al. (1981) study, about half the subjects in the 2D group interrupted their reading. In contrast all the 3D subjects did this. While interrupting reading is a useful strategy for gaming visual information, the overall pattern displayed by the 3D group appears to be one of distracted behavior which was reflected in the lower test scores for this group. This concurs with Dwyer's (1970) finding that extra details in realistic visuals sometimes served as distractors rather than enhancers, causing students to miss more important visual or textual cues.

It is interesting to note, as did Flagg et al. (1981), the various strategies used to study the stimuli. Out of 60 instances (20 students x 3 stimuli) 52 ended with the visual. For the 2D group, 28 of 30 instances began with the text; 18 of these involved students moving from the text to the visual without interruptions. This "business first" approach points to our educational emphasis on information being derived from the text, with illustrations for enjoyment rather than learning. In contrast, the 3D group was so distracted by the illustration that 21 out of 30 instances began with the visual and there were no cases of text-to-visual without interruptions.

Had this high amount of visual fixation time led to increased recall of information from the illustrations, the more realistic three-dimensional illustrations might have merited more support. However, the 2D group scored significantly higher on T and P+T questions, and the difference between the two group scores for P questions was just shy of significance ($p<059$) with the 2D group again scoring higher. Given the amount of time spent studying the illustrations, it is surprising that the 3D group did not remember more information. Perhaps this tendency to fixate on the illustration reflected simple visual appeal, interest, or novelty (as in Faw and Nunnally, 1967,1968; Mackworth and Morandi, 1967). These results are contrary to Dwyer's (1970) finding that highly realistic visuals tended to increase learning when study time was self-paced. In the present study three-dimensionality as an example of realism only served to distract learners, leading to lower retention.

It should be noted that even with the significant difference between the retention test scores for the two treatment groups, those for the 2D group were just passing (mean of 72.9% correct), while the 3D group had a mean score of 57.3%. Several factors might have contributed to these results. Perhaps some learner variable was contributing to the retention scores. The subjects did not know they were taking a test after reading, and their scores might have improved had they known. Also, design variables might be manipulated in future research studies to determine their roles. For instance, text placement, illustration placement, and the relative sizes of text and illustration might all be varied. Another possibility might be to integrate the text more fully into the illustration, rather than having a clear demarcation between text and illustration. Short sequences of text could be used in various sections of the layout rather than one long column of text. Manipulating some of these factors might yield more favorable results, though it is possible that the kind of realism displayed in three-dimensional illustrations would simply prove to be distracting and inappropriate for this task. Dwyer (1970) cautioned that an illustration which attracts the reader does not necessarily serve a cognitive function as well, and the results of this particular investigation indicate that three-dimensional illustrations seem to serve the former goal better than the latter.

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Appendix A. Sample of Test Questions Per Stimulus

Stimulus # 1 Cro-Magnon Homes

Cro-Magnons built various types of homes because
a) people had personal preferences.
b) they had to adapt to their environmental conditions.
c) priests and tribal leaders lived in different dwellings than other
d) all of the above.

Some Cro-Magnon houses faced south
a) for religious purposes.
b) to take advantage of solar heat.
c) for ventilation.
d) to have access to a communal fire.

Stimulus #2 Cro-Magnon Art

The cave paintings mostly show
a) animals.
b) people.
c) landscapes.
d) dwellings.

The purpose of Ihe cave paintings was most likely
a) religious worship.
b) decoration.
c) magic.
d) art.

Stimulus # 3 Cro-Magnon Technology

To cut meat from the animal, the Cro-Magnons used tools made of
a) many small stone blades.
b) slotted stones.
c) several sharp antlers.
d) mammoth bones.

During the hunt, Cro-Magnons used flaming torches to
a) separate one animal from the herd.
b) force animals into close groups.
c) attract animals.
d) injure animals.

AUTHOR

Farough Abed is Associate Professor, Educational Leadership and Communications Technology at Central Connecticut State University, New Britain, CT.