Variables Affecting the Legibility of Computer Generated Text

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Abstract. The effects of three text layout variables—justification, line length, and leading, are examined. Text presented on computer display terminals is read faster when the text is left justified, characters are small, and lines are long and separated by blank space. Although each of the variables affects the efficiency of reading text and may also have affective consequences, the overall effect of each on learning outcomes may be negligible.

Much has been written concerning the effects of printed text on comprehension and reading speed. Recently, however, as the price of paper has increased and the cost of computers has decreased, the use of the computer display terminal to display computer generated text has become more widespread (Merrill, 1982).

With the rapid growth of the computer in society, many have suggested that much of the present printed text will be presented on computer displays (Jonassen, 1982; Lancaster & Warner, 1985; Muter, Latremouille, Treurniet, & Beam, 1982). However, research suggests the readability of computer displayed text is often impaired. Computer displayed text is often read more slowly than the same text presented in print form. In some cases, studies have demonstrated that computer displayed text is read as much as 20%-40% slower than the same text in print form (Gould & Grischkowsky, 1984; Kruk & Mutter, 1984; Muter, Latremouille, Treurniet, & Beam, 1982; Wright & Likorish, 1983). However, little evidence exists to predict the effects of display differences on comprehension.

Nonetheless, since considerable amounts of text must be presented on computer displays, it is important to optimize reading efficiency of such text. One of the principal reasons for presenting text via the computer display is to capitalize on the interactive capabilities of the computer (Jonassen, 1982). However, not all material presented through the computer display requires these interactive capabilities. If reading speed of computer displayed text cannot match the reading speed of paper text (assuming similar levels of comprehension in each case) and the interactive nature of the computer is not utilized, it is doubtful that the computer display will rival paper as a medium for displaying large amounts of text. Consequently, it is essential that the optimum conditions of computer displayed text presentation are identified and employed.

The purposes of this paper are (a) to review the effects of three text display variables—justification, line length, and leading—on reading speed and comprehension; (b) to analyze critically current literature in each area; and (c) to describe the implications of such findings for the design of computer based instruction.

Text Display Variables

In order to identify the optimum conditions for presenting computer displayed text, it is useful to first examine research derived from printed text (Spannaus & Pariseau, 1985). The presentation of computer displayed text will likely incorporate some of the psychological principles derived from the investigations featuring printed text. However, due to the nature of the medium, differences are also likely to be found (Reilly & Roach, 1986; Simpson, 1984). For example, with the computer display, fonts comprise discrete dots or pixels as opposed to continuous lines, and can be more difficult to decode. Consequently, care must be exercized in generalizing conclusions concerning printed text to computer displayed text.

Justification

One area of text layout that has received comparatively little attention is that of text justification. There are several methods for justifying text on a computer display. In this paper, the three methods illustrated in Figure 1 will be examined: fully justified, left justified, and center justified text.

Definitions. Full (or fill) justified text features lines of equal length. The spacing between the words is varied and words are sometimes broken at line endings to achieve this goal. Left justified (or right ragged) text features varied line lengths, uniform spacing between words and complete, unbroken words at line endings. Center justified (or balanced) text is balanced with respect to an imaginary vertical line, which extends down the center of the page (Hartley, 1978).

Bork (1984) considers left justification of text to be essentially a method that evolved from printed text. He has argued that left justification is usually an undesirable practice when presenting computer text, noting that blank space is essentially free with the computer display and that text should be center justified in complete phrases.

Eye movement. In an investigation into the effect of text manipulation on paper, Keenan (1984) examined the effect of variable line length on reading speed. In the investigation, the relationship between the return sweep and line length variability was studied. The return sweep is the movement of the eye from the end of one line to the beginning of the next. Keenan concluded that line length variability disrupts eye movements. When margin position varies, return sweeps are often inaccurate resulting in undershoots or overshoots, and must be compensated for by the eye. The compensatory eye movement required to place the beginning of the line in foveal vision (the region of the retina where vision is most acute) is called a corrective regression (Morrison & Inhoff, 1981; Rayner, 1978). The time length of a saccade, the eye movement required to bring new text into foveal vision (Rayner, 1978), necessary to perform a corrective regression is equal to the length of time taken over a normal saccade, roughly 30-125 milliseconds. Consequently, variable positioning of the margin will cause inaccurate return sweeps, which in turn result in increased reading time.

Reading speed. According to Leisman (cited in Keenan, 1984), fully justified text helps the reader to construct an internal map that performs the return sweep automatically. If true, variable line lengths of balanced text may hinder the development of the internal map and, consequently reduce reading speed. Even if this hypothesis is disproven, balanced text may still reduce reading speed. With balanced or centered text, variable line beginnings are common. In effect the fixation point for text varies from line-to-line, providing no consistent reference point. Thus the reader may be unable to perform return sweeps automatically. Under these circumstances reading speed will decrease due to the increased number of corrective regressions that must occur.

Hartley (1982) disputed the wisdom of balancing text around a central axis. He cautioned that when text is not left justified, reading difficulties for both young and old readers are more likely to occur. Inconsistent placement of the left margin serves only to confuse the reader unnecessarily. In a related study, center justification was found to make drug labels difficult to read, which in turn caused nurses to make errors in locating drugs (cited in Hartley, 1978). Once left justified, the labels were read more easily and nurses made fewer errors.

In a different study regarding reading speed and justification, Trollip and Sales (1986) found fully justified text presented on a computer display to have a detrimental effect on reading speed compared to left justified text. They determined the length of a fixation, the period when visual information is transmitted through the eyes (Rayner, 1978), to be a constant for the reader. The number of characters, whether letters or spaces, perceived during a fixation does not change. Consequently, fully justified text, into which spaces have been inserted to achieve full balance, causes more fixations in order to read

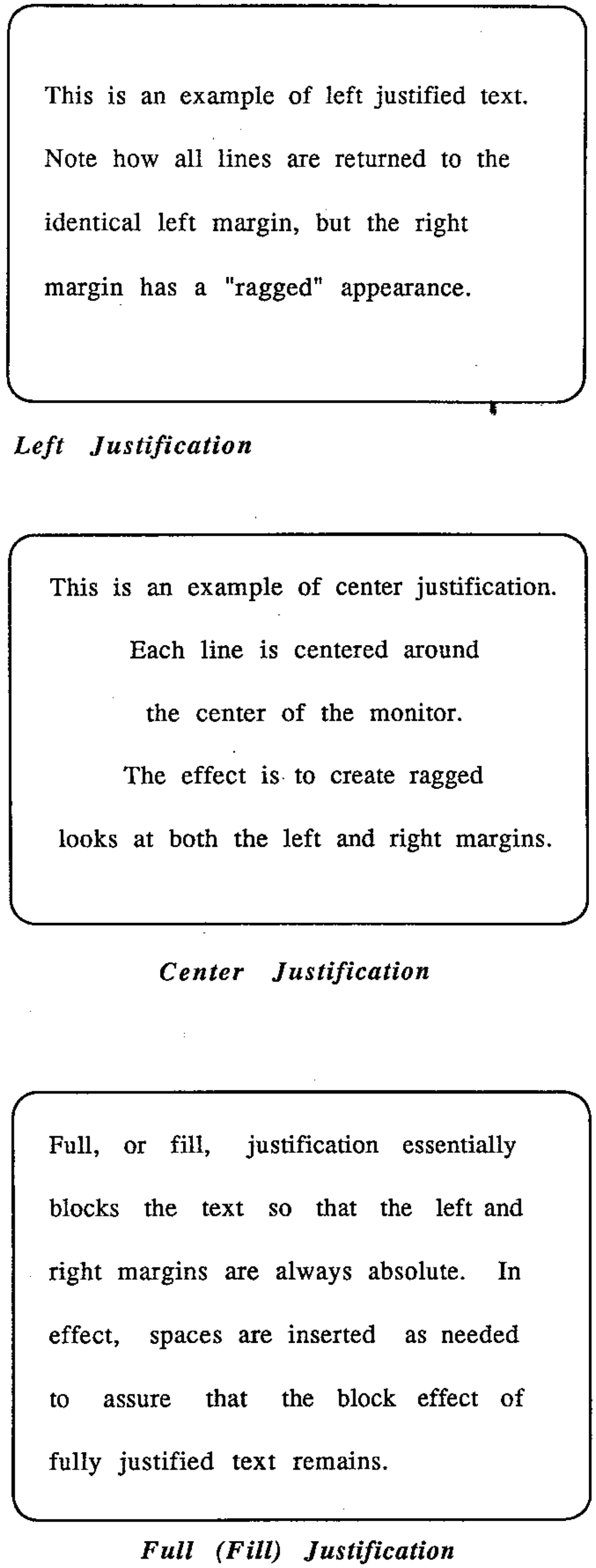

Figure 1. Sample justification formats for computer displayed text

the same amount of text, and lowers reading speed. This idea is supported by several psychophysical experiments (Morrison, 1983; Morrison & Rayner, 1981), which suggest that the perceptual span is constant when moderate changes in the viewing distance are introduced. The perceptual span is the area close to the center of vision, in which visual details affect reading (McConkie, 1983). Perceptual span may be important in guiding readers' eye movements and in helping the reader to integrate information from one fixation to another (Rayner, 1978).

A related implication of placing extra spaces between words is to vary the point to which the eye must move to find the next word. This will also reduce reading speed (Trollip & Sales, 1986). Variable placement of word beginnings may require the reader to make more decisions as to where a word starts. These extra decisions will probably result in increased reading time. The implication of this research is that fully justified text should be avoided for the presentation of text on a computer display.

Indentation. Another area of research related to justification is that of paragraph indentation. On printed text, indenting the first line of a paragraph significantly improves legibility (Tinker, 1963). Grabinger (1985) supported these findings for computer display text, noting subjects generally preferred paragraphs that were indented. However, although positive, the influence of paragraph indentation was modest. Through paragraph indentation, margin variability is increased but so is reading speed. However, this does not necessarily contradict findings regarding irregular margins. It is hypothesized that the periodic but systematic indentation of a new paragraph acts as an information organizer that helps to clarify lesson information, and thus to improve reading speed.

Summary of justification theory and research. Although most of the research cited focused on printed text, several findings appear relevant to computer displayed text. Left justified text, for example, may be preferred to either center or fully justified text, although the benefits may be inconsequential with regard to actual learning. Advocates of centered text consider the layout aesthetically pleasing, thus more motivating and easier to read than left justified text. It may be that such advantages outweigh the disadvantages of disrupted return sweeps.

Line Length

Another area of interest concerning text layout is optimum line length. Line length can be divided into two areas: Character density and the number of characters per line. These are illustrated in Figure 2.

Character density. Character density refers to the maximum number of

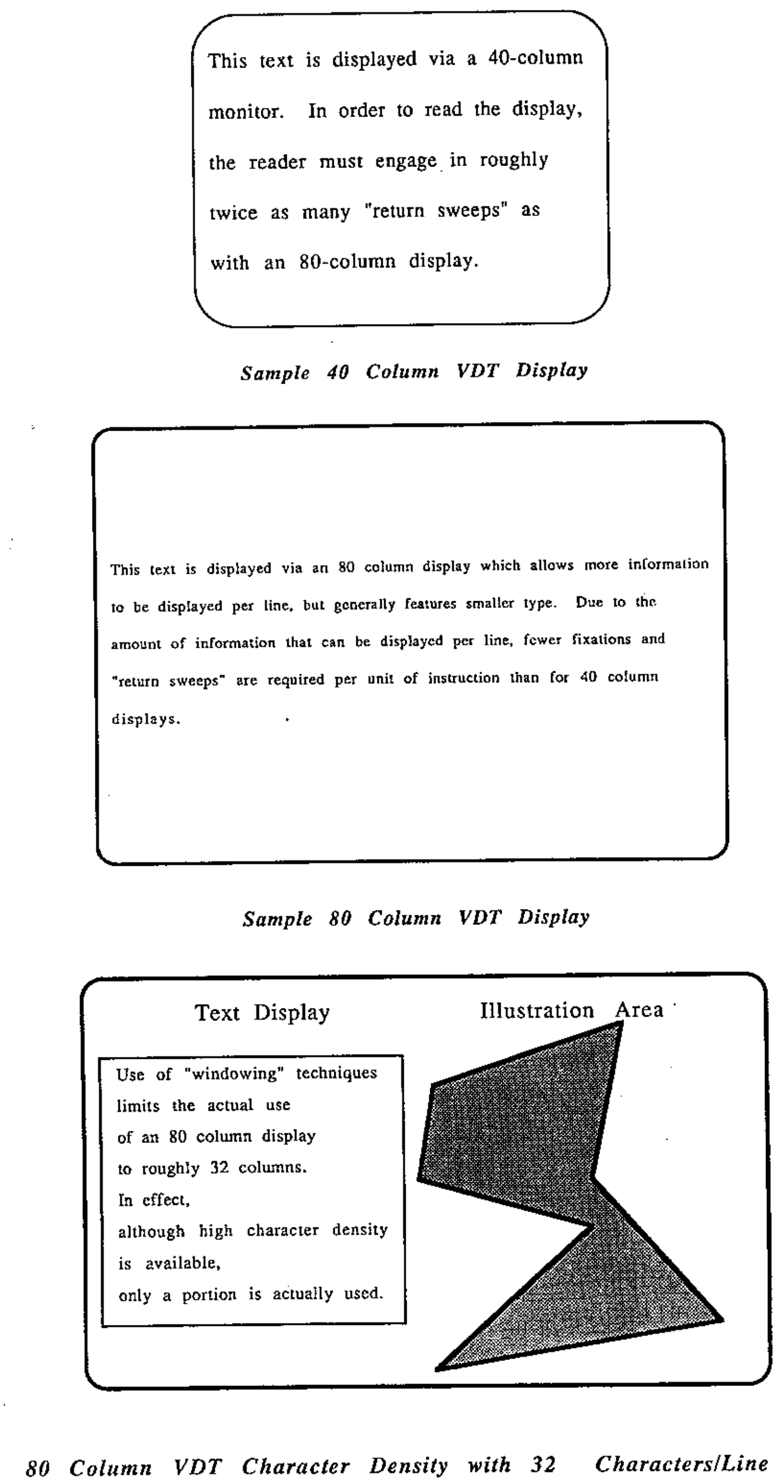

Figure 2. Samples of 40 and 80 character density and computer display usage

characters that can be displayed legibly on a single horizontal line. On a computer display the character density is usually either 40 or 80 characters per line. The number of characters per line refers to the maximum number of spaces actually used to present information. For example, on a line with a character density of 80 characters an author may choose to use only columns 11-70 on which to present text. Consequently, the resulting number of characters per line would be only 60 versus the 80 character capability of the computer display. This practice of using only part of the screen to display text is known as windowing. Windowing limits the amount of text that may be presented on the screen and may make the screen more pleasant to look at. While most authors appear united on the optimum character density used to present computer displayed text, considerable differences exist concerning the optimum number of characters per line.

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With regard to printed text, Tinker (1963) concluded that medium size (11 point) print was read more efficiently than both smaller and larger sizes of print. Computer displayed text legibility is often affected more by equipment limitations than by type size. Text presented on a computer display is often limited to 40 (or 80) columns and 24 rows, resulting in a maximum screen display of approximately 1,000 characters (2,000 characters for 80 columns). Each different character is created by illuminating a unique configuration of pixels in the allocated character grid. The acuity of each character is determined by the number of pixels used to create each character. The more pixels illuminated, the sharper the definition of the character. Consequently, large and small print, designed on large character grids and made up of many pixels, may be more legible than medium size print designed on a small character grid.

Eighty characters per line is often preferred to 40 characters per line for presenting computer displayed text (Hathaway, 1984; Heines, 1984; Duchnickey & Kolers, 1983). Kolers, Duchnicky and Ferguson (1981) suggested that dense text, presentation is often preferred since fewer fixations are required to read smaller characters. Although these fixations are longer than for moderate density passages, they are more efficient for the densely packed text. Duchnickey and Kolers (1983), in a related conclusion, suggested that larger characters subtend a greater viewing angle than smaller characters. That is, larger letters require a greater proportion of the total viewing angle to be used for the fixation. Consequently, readers have fewer characters in their perceptual span. Thus larger characters that reduce perceptual span may also reduce reading efficiency.

Number of characters per line. Some recent research into optimum characters per line for the computer display appears to contradict research for printed text. In his early work, Huey (1908) noted that shorter lines were generally preferred to longer lines for printed text. He claimed that the maximum line length should be roughly 9 cm—10 cm. Longer lines were alleged to cause inaccuracy on the return sweep; shorter lines allowed the reader to use peripheral vision to see what had passed as well as what was forthcoming.

Tinker (1963) reported that readers preferred moderate line lengths over both short and long lines. Long lines tend to result in frequent undershoots on return sweeps and complications in identification of the correct lines. Short lines, those containing fewer characters, tend to make inefficient use of peripheral vision and fail to stretch the perceptual span. Stretching the perceptual span results in a reduction in fixation duration and an increase in saccade length, which together cause an increase in reading speed. Optimum length lines stretch the perceptual span to its capacity.

Opinions vary greatly concerning the optimum number of characters per line of computer displayed text. One belief is that lines of text displayed on a computer display should be kept short. Bork (1984), for instance, stated that long lines are not needed in computer-based materials. He noted that readability research derived from printed text supported this position. Heines (1984) believed that line length was an important factor affecting text readability: The shorter the line on the computer display the easier to read. It was suggested that lines on the display should contain fewer words than when presented on paper.

Another perspective suggests that computer displayed text is read most efficiently when lines are long. Duchnickey and Kolers (1983), for example, determined that lines ranging from 2/3 to full screen width were read equally well, and were read significantly faster than text presented at 40 characters per line. In this experiment, lines of length 52 characters and 78 characters were read much more efficiently than lines of 26 characters. Consistent with results from paper text, it might be expected that the 52 character line would have been read more efficiently than both the long and short lines. This suggests that in certain cases text display principles vary from print to computer display.

In another study, Grabinger (1985) found that longer lines (60 characters per line) were generally (but not strongly) preferred over shorter lines (40 characters per line). Although empirical evidence indicates that longer lines of text are read more efficiently than shorter lines, it is possible that shorter lines may have a greater affective influence on learning.

An alternative opinion concerning line length has been expressed by Frase and Schwartz (1979). They noted that optimum line length was of little practical or cognitive importance. Other variables, such as text segmentation (the implementation of line breaks according to natural language sequences), had far more influence on the readability of text. Segmentation helped to organize information for the reader thus improving the flow of information from short to long term memory. Improving the storage of information in long term memory results in more efficient recall and consequently facilitates higher level cognitive activities. This position has also been advanced by Bork (1984).

Summary of line length theory and research. Clearly, additional research concerning line length is required before definitive conclusions can be drawn. It appears that text is read more efficiently when presented in a dense manner. However, precisely what constitutes optimum density is a matter of conjecture and must be determined empirically. In general, when given the opportunity to present text at 40 or 80 character density, denser text appears preferable.

The issue of the optimum number of characters per line of computer displayed text also remains unresolved. Recent research suggests that the research and theory of the number of characters per line for printed text does not generalize to computer displayed text. Research is required to extend the work of Duchnickey and Kolers (1983) and Kolers, Duchnickey and Ferguson (1981) to determine the importance of the number of characters per line for the computer display. If necessary, guidelines for determining the optimum number of characters per line need to be established. It must also be determined whether character density and characters per line operate interactively when text is presented on a computer display.

Leading

Leading is the insertion of space between lines. Leading is often referred to as single or double spacing of lines of text. Examples of leading, and the effects on legibility, are shown in Figure 3. Early research with printed text supported the notion that leading improves legibility, though often the improvement was not found to be significant (Huey, 1908).

The results of recent research, however, have revealed that leading has an important influence on the legibility of text. It may increase perceptual span by reducing the effects of lateral masking (Tinker, 1963). Lateral masking distractions are caused by characters in adjacent lines, thereby interfering with peripheral vision (Kruk & Muter, 1984; Van Nes, 1986). Peripheral vision is important since it may help to guide the readers eye movements and integrate information from one fixation to another (Rayer, 1978).

With printed text, the insertion of blank space between lines decreases the amount of text per page and consequently increases the cost of book production. With a computer display the insertion of blank lines of space adds nothing to production costs (Bork, 1984) and may improve reading speed (Sweeters, 1985).

Studies related to the effects of leading on reading computer displayed text generally support the findings from printed text. Hartley (1979) stated that for printed text the optimum space between lines of text is obtained by inserting a line of space equal in height to the width used for word spacing.

Reading efficiency has also been shown to improve when text presented on a computer display is double spaced as opposed to single spaced (Hathaway, 1984; Kolers, Duchnicky & Ferguson, 1981; Kruk & Muter, 1984). With single spacing, more fixations per line are required. Each fixation contains fewer words and, consequently, reading time is increased. Again, however, differences in reading speed were of little practical importance (Kolers, Duchnicky & Ferguson, 1981).

Single Line Spacing

Line leading or spacing can affect the legibility of the VDT display. Text displayed via single spacing can be crammed and difficult to read. Increasing the line spacing often increases legibility.

1 1/2 Line Spacing

Line leading or spacing can affect the legibility of the VDT display. Text displayed via single spacing can be crammed and difficult to read. Increasing the line spacing often increases legibility.

Double Line Spacing

Line leading or spacing can affect the legibility of the VDT display. Text displayed via single spacing can be crammed and difficult to read. Increasing the line spacing often increases legibility.

Figure 3. Effects of leading on computer display legibility

Text is read more efficiently when presented in a dense manner. In general, present text at 40 or 80 character density.

Other research on computer displayed text suggests an interaction between leading and character height. Some authors have suggested that single spacing should be avoided on displays where leading is small in proportion to the height of the characters. Single spacing can increase lateral masking (Kruk & Muter, 1984).

The minimum ratio between line distance and line length has been defined precisely. Line distance is the distance between the lines that "connects the bottoms of short letters in two consecutive text lines" (Van Nes, 1986, p.100). Line length is the length of a line of text presented on the computer display. The minimum ratio of line distance to the number of characters per line should be .033 (cited in Van Nes, 1986). For example, if a text line measures 21.5 cm and the line distance is 0.8 cm the resulting ratio is an acceptable 0.037. With a lower value, characters can cause a masking effect that hinders word identification. This masking effect can be removed by either increasing the distance between lines or by decreasing the number of characters per line. Both have the effect of improving text legibility. Van Nes noted that a 20% reduction in the number of characters per line of single spaced text from 40 to 32 characters should increase legibility considerably.

In reality, vertical line spacing on the computer display is usually limited to complete text lines of blank space. One of the dangers of using whole lines of blank space to separate text is that the display potential of the screen is severely, if not unacceptably, impaired. Therefore, the designer is often severely limited as to the exact amount of space that can be displayed between lines (Reynolds, 1982).

Summary of theory and research in leading. Leading appears to improve the reading speed of text presented on a computer display. When text is presented at more than 40 characters per line, readability is often improved if lines of text are presented double spaced.

However, other factors may be of equal or greater importance. The use of blank space may be a more important variable than leading for the presentation of computer displayed text. For example, when studied independently, leading may reduce reading speed since it results in text that is more spacious.

Implications for the Design of Computer-Based Instruction (CBI)

1. *If the options exist, left justification should be chosen over both center and fully justified text.* Left justified text is read faster than both center and full justified text. However, the advantages of using left justified text may well be outweighed by other variables of text design.

2. *When possible, text should be presented at a character density of 80 characters as opposed to 40 characters per line.* Assuming comparable legibility, text is read more efficiently when presented in a dense manner. Research is needed to determine exactly what text density is read most efficiently. It must also be determined if character density interacts with reading ability to affect reading speed of computer displayed text.

3. *Within practical limits, text should be designed to feature greater numbers of characters per line.* Longer lines of text are generally read more efficiently from the computer display than shorter lines. However, there are undoubtedly limits, after which characters are no longer legible. These limits must be determined empirically. It must also be determined whether all readers prefer greater numbers of characters per line or whether for some, beginning readers for example, shorter lines of text are read more efficiently.

4. *Leading of text should be increased as text density increases.* As character length increases, the effects of lateral masking make text more difficult to read. Text presented at a character density of more than 40 characters per line should always be double spaced.

5. *It may well be that the measurable effect of each of the variables on learning is minimal.* However, the overall effect of reading text from a screen that is pleasant to look at may in itself have positive transfer to learning. Designers of computer based instruction are virtually unaffected by cost limitations when organizing text display. Consequently, the potential impact of different modes of presentation may be considered, without fear of increasing production cost, while possibly capturing the readers' attention and helping to organize information. This may result in text that is both easier to read and better organized in long term memory.

Closing Comments

Although limited research has been conducted in computer displayed text design, additional research is needed. At present, designers are often hindered by the lack of research relevant to computer-based instruction. Designers of computer-based instruction are forced to either assume that research on printed text design will transfer to computer displays, or to rely heavily on intuitive beliefs. Identification of the principles of text design that are consistent with print research must be established. Where inconsistencies exist, the unique attributes of computer displays must be verified.

It is important that systematic efforts to identify relevant design variables are advanced. However, screen layout variables are frequently affected more by computer system limitations than by "ideal" display specifications. In many cases, learning outcomes per se may be only minimally affected by the manipulation of text display variables. Variables may affect the immediacy of text recognition, for example, but may have little impact on learning. The task for the instructional design profession is to identify relevant variables that influence the effectiveness and acceptability of computer displays.

Finally, it is worth noting that several other areas of text design likely to affect computer displayed text legibility exist. These include variable letter spacing (where the spacing between letters is allowed to vary according to the width of the characters), text segmentation, headings to highlight a change of subject, the use of blank space to separate text, emphasis attributed to hypertext techniques, and the use of color for amplification. Each of these variables has the potential to influence learning from computer-based instruction. While the purpose of this paper was to examine the three selected variables, these are not necessarily the only computer display variables likely to influence learning. Future efforts to clarify the effect of computer display differences need to address the full range of display options.

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