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Quantitative Graphical Display Use in a Southern U.S. School System

John V. Dempsey, Samuel H. Fisher, III, and Judith B. Hale
University of South Alabama

This paper reports the results of a survey of 429 teachers in an urban, racially mixed Southeastern school district. The survey elicited teacher perceptions of the value of using graphs and charts, when and how they taught and used graphical information, and how they themselves were trained in the use of graphical displays for instruction. Overall, the use of graphs is most prevalent in elementary schools and decreases as grade level increases. Although teachers perceive that students pay more attention to graphical information, most subject areas (excluding mathematics) report relatively infrequent use (one-third or lower) of these visuals in instruction. Teachers also perceived that it was more important to understand or use charts than to be able to construct them. Approximately one-half of the teachers surveyed reported receiving no training at all in the use of graphical displays. Findings are discussed with respect to Paivio's (1986a) dual coding theory.

In primary, middle, and secondary schools in the United States a vast amount of quantitative information is presented to students. Some of this information is presented in a body of work or in tables where the relationship between the numbers and the ideas is not clearly obvious. In other situations, graphical displays (charts, graphs, and related spatial or metaphoric representations of numeric data) are used in an effort to make quantitative relationships more concrete or easily interpreted.

Often, graphs are analyzed either by recognition (bottom-up processing) or by searching (top-down processing). Some tasks require a combination of recognition and search strategies (Brasell, 1990). Graphs may also be constructed by learners, either conventionally or using a graphing calculator or computer to construct graphs in "real time." These three actions that a learner may choose (i.e., recognize, search, or construct) are paralleled to some extent by the kinds of questions that a graph may be used to answer. Bertin (1973) and Wainer (1992) suggest that there are three levels of questions that a graph may answer: elementary level questions involving simple data extraction; intermediate level questions involving trends in the data; and overall level questions involving an understanding of the deep structure of the data.

John V. Dempsey is Associate Professor of Behavioral Studies and Educational Technology in the College of Education at the University of South Alabama. Samuel H. Fisher, III is Associate Professor of Political Science at the University of South Alabama. Judith B. Hale is a doctoral student in the Instructional Design and Development program at the University of South Alabama. Please address correspondence regarding the paper to John V. Dempsey, 3700 University Commons, University of South Alabama, Mobile, AL 36688 (e-mail: jdempsey@usamail.usouthal.edu).

Why Are Graphical Displays Used?

Graphical displays are used in many situations to represent large amounts of information concisely. They are particularly effective in showing intercomponent relationships and sequences (Moore, 1993). When used with more abstract textual information, they present a visual mode of information and therefore have the potential for encouraging dual coding (Paivio, 1983) or conjoint retention (Kulhavy, Lee, & Caterino, 1985). Dual coding theory, for example, suggests that information is represented in two fundamentally distinct systems. One of these systems is suited to verbal information and the other toward images. Paivio (1986a) suggests that incoming information can be coded in one or both systems. Information encoded in both systems would be enhanced compared to information encoded in only one of the systems. In addition, Paivio hypothesized that the nonverbal components of memory traces, which would include graphical displays, are often much stronger than verbal memories (Paivio, 1986b; Paivio & Csapo, 1975).

Some theorists suggest that graphical displays decrease processing demands in working memory that leaves cognitive resources for higher level operations such as the development of semantic macrostructures (Winn, 1991). Others promote the notion that understanding or constructing diagrams or graphs using learning strategies such as visual imagery provides a perceptual supplement for gaining insight into acquiring symbolic thinking essential for learning abstract concepts or mathematical problem-solving (Lin, 1979).

Certainly the use of graphical displays is widespread both in schools and in later life. Cleveland (1984) reports that approximately one-third of the space in some scientific journals is devoted to graphs. He emphasizes their importance by contending that readers who do not scan scientific papers in detail are drawn toward graphs to extract information.

Whether graphical displays alone increase instructional effectiveness is debatable. Some researchers (e.g., Feliciano, Powers, & Kearl, 1963) suggest that graphs are more effective than tables or text for communicating numeric information, while other researchers (Vernon, 1950) offer evidence that contradicts this assertion. More likely, instructional effectiveness would result from a combination of instructional modalities and strategies (Kourilsky & Wittrock, 1987) and appropriate use of graphic design principles (Felker, 1980; Tufte, 1983). Some available research has been heavily criticized for poor experimental design or test validity (MacDonald-Ross, 1978) and a lack of a theoretical framework (Reynolds & Baker, 1987). Even so, there are some thoughtful guidelines for interpreting or constructing graphs available from several sources. Prominent among these are the texts of Cleveland (1985), Hartley (1995), Kosslyn (1994), Schmidt (1983), and Tufte (1983, 1990).

Teachers' Reports of Graphical Display Use

Both teachers and theorists posit that students understand graphs poorly. When Barkley (1987) presented 125 seventh and eighth graders with the simple graphing question shown in Figure 1, sixty percent chose answer B instead of the correct answer--A.

Jan walks away from a mark on the floor at a steady rate and then walks back toward it. Which distance graph below would best describe her walk?

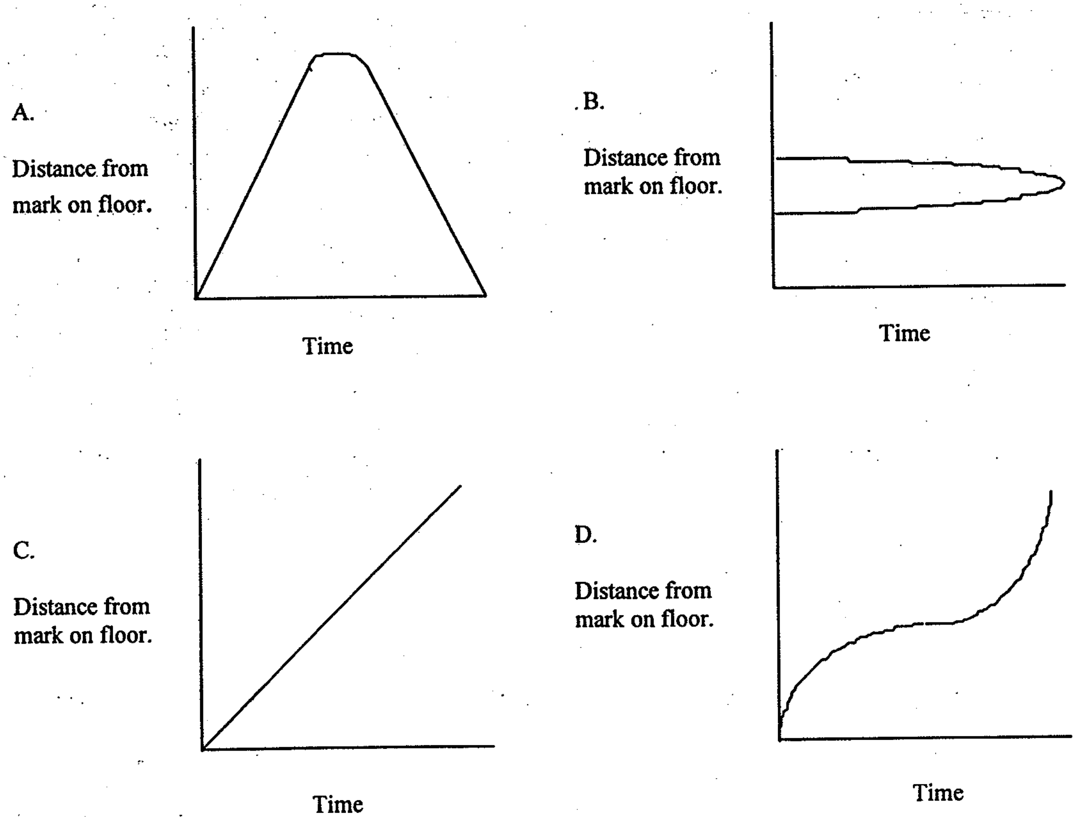

Figure 1. Adapted from Barkley, T. (1987, February). A graph is worth how many words? *Classroom Computer Learning*, p. 46.

This survey sampled K-12 teachers in a large Southern US school district regarding the use of quantitative graphical displays in public schools. Scant current information exists in the literature regarding chart and graph usage in the schools. Even more meager is the baseline information regarding that which students have had an opportunity to learn in school. Information about how teachers use graphical displays in varying subject content and in different grade levels is limited, although there are some materials available. For example, Brasell (1990) contends that in science areas, graphing is generally taught at the elementary level (p. 72). Although this type of anecdotal information, related national tests (NAEP, 1985), and state guidelines are somewhat illuminating, teachers have rarely been asked to honestly report information about graphical instruction and learning where their anonymity was protected.

The survey itself dealt with 12 major topics including use, familiarity, and interpretation problems. Teachers were queried about how they used charts, how they were trained to use charts, which charts they employed most frequently, and which charts they believed to be appropriate for student use. Teachers were also questioned about how students should use charts and what learning strategies students used to understand charts. They were asked when and in what content areas students should be introduced to charts. Finally, teachers were asked to describe how they taught students to analyze and construct charts. Because a pie chart, for example, is also called a circle graph, and to simplify our communication with teachers, we defined a "chart" or "graph" as any graphical display of quantitative data. We acknowledge that the present study is limited to teachers' reports of what occurs in schools.

Method

Subjects were 429 teachers from a large southeastern school system. The subjects taught kindergarten through 12th grade in a variety of subject matter. Sometimes an instructor would teach in as many as three different content areas. The schools in the system were grouped into elementary, middle, and high schools. Based on proportionate student population, seven schools were randomly selected from the elementary school list (including Kindergarten teachers, $n = 250$), four middle schools from the middle school list (grades 7 and 8, $n = 58$), and four high schools from the high school list ($n = 121$) of the system's schools. Due to some teachers' concerns about anonymity, age of the subjects, gender, and ethnic composition were not collected. According to system administrators, however, the schools represented a cross section of racial and rural/urban composition. In the fifteen schools from which the sample was drawn, 24% of the teachers were female, 76% were male, 28% were African-American, and 72% were white. Participation by teachers in this research was voluntary, however, as the data was collected during the teachers' regularly scheduled meeting or inservice periods and had the backing of school administrators, none of the teachers declined to participate. Approximately 54% of the teachers in the surveyed schools attended these inservices. Teachers were assured, in writing, that all data gathered would be completely anonymous. Most participants were experienced teachers (M years teaching = 12.7, $SD = 8.9$). The highest level of educational achievement of the teachers was a bachelor degree (51%), 48% had attained a masters degree, and 1% had a doctoral degree. Mean class size was 30, $SD = 22$.

Instrument and Procedures

A 78 item survey (including eight open-ended items) was designed to measure the use of quantitative displays in the schools. It was piloted with thirty experienced K-12 instructors and revised based on their comments. The instrument was administered on location, usually during teacher in-service meetings. Subjects were introduced to one of the experimenters, usually by the principal of the school. The experimenter gave a short description of the goals of the survey while a one-page information sheet and the survey itself were distributed. After the researchers answered questions, usually relating to the use of their responses, teachers took approximately twenty minutes to complete the survey.

Results[1]

Use of Charts in Teaching

A slight majority of teachers (55.3%) use graphical displays often or very often in their teaching. Thirty-eight percent of the teachers used charts sometimes. Only 6% reported not using charts at all. As Figure 2 indicates, there was a much more frequent use of charts by instructors in kindergarten and elementary grades than in junior high and senior high schools ($\chi^2 = 51, p < .001$).

[1] Summarized responses to the 78-item survey and the marginals for survey questions may be viewed at http://www.coe.usouthal.edu/techReports/notes.html (technical report #96-2)

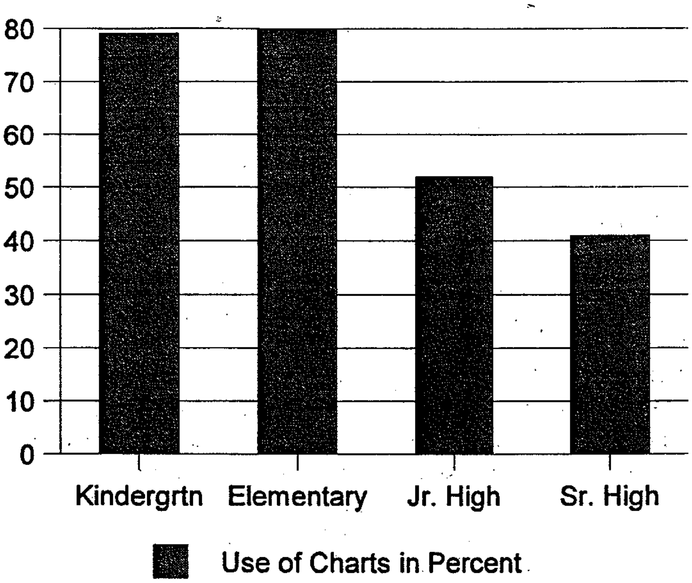

Figure 2. Use of charts by grade level.

Problems in Interpreting Charts

Teachers reported some common problems students had in correctly interpreting charts were: recognizing that chart intervals are scaled using standardized units (reported by 38.9%), recognizing patterns or trends in charts (35.7%), converting a point on the chart to a number (26.3%), and numerically comparing two different points on a chart (23.8%). See Table 1.

Table 1
Problems in Interpreting Charts

Do not recognize standardized units	38.9%
Do not recognize patterns (trends)	35.7%
Do not understand chart axis interval	34.5%
Convert chart point to number	26.3%
Cannot compare two points on chart	23.8%

Familiarity with Charts

About half (51.7%) of the instructors reported that they knew students had used charts before entering their class. Only 10.5% of the instructors reported that students had not used charts before entering their class. Instructors reported students were most familiar with bar charts (53.4%), followed respectively by pie charts (31.5%), line charts (29.84%), and combination charts (18.2%).

Ease of Use

Bar charts were reported to be easy or very easy for students to understand by 68.5% of instructors. Line charts, pie charts, and combination charts were reported to be easy or very easy for students to understand by 44.3%, 42.2%, and 23.3% respectively.

Charts Employed Most Frequently

Of the four types of charts considered in the survey, bar charts were reported to be used most frequently for instruction (78.8%); followed by line charts (52.0%); pie charts (48.7%); and lastly, combination charts, e.g., bar and line (37.5%).

Appropriateness for Student Use

Instructors recounted that bar charts were the most appropriate for student use (60.1%), followed by line charts (33.6%), pie charts (28.7%), and combination charts (35.9%).

Table 2
Charts Reported by Teachers to be Most Familiar, Used Most Often, and Most Appropriate for Students

	Most Familiar	Used Most Often	Most Appropriate
Bar	53.4%	78.8%	60.1%
Line	29.8%	52.0%	33.6%
Pie	31.5%	48.7%	28.7%
Combination	18.2%	37.5%	35.9%

Learning Strategies

Visualization was reported by instructors to be the most common strategy that students used to understand charts (69.5%), followed by demonstration and practice (54.5%), and concrete examples (47.1%). Only 11% of the instructors expressed that students used metaphors or analogies to understand charts.

In terms of effectiveness, visualization was considered effective or very effective by 79.1% of the instructors, concrete examples by 79.7%, and demonstration/practice by 78.8%. Metaphors and analogies were considered much less effective, with only 35.4% of the instructors considering that strategy to be effective or very effective.

Visualization, demonstration/practice, and concrete examples were considered helpful strategies for students to employ when using charts by 66.2%, 63.9%, and 66.2% of the instructors respectively. Again, metaphors and analogies were only considered helpful by 35.2% of the instructors. The use of any learning strategy to understand data presented in charts, however, declines as grade level increases.

Table 3
Learning Strategies Considered by Instructors to be Most Used by Students; Most Effective in General; and Most Effective for their Students to Use

	Strategies Used by Students	Most Effective Learning Strategy	Most Effective for Students
Visualization	69.5%	79.1%	66.2%
Concrete examples	47.1%	79.7%	66.2%
Metaphors/Analogies	11.1%	35.4%	35.2%
Demonstrations	54.5%	78.8%	63.9%

Combining Charts With Text

Greater than half (52.4%) of instructors reported students paid more attention to text combined with charts. Some instructors were unable to tell any difference (33.1%). Only a small percentage (7.7%) of instructors indicated students paid less attention to text with charts. See Figure 3.

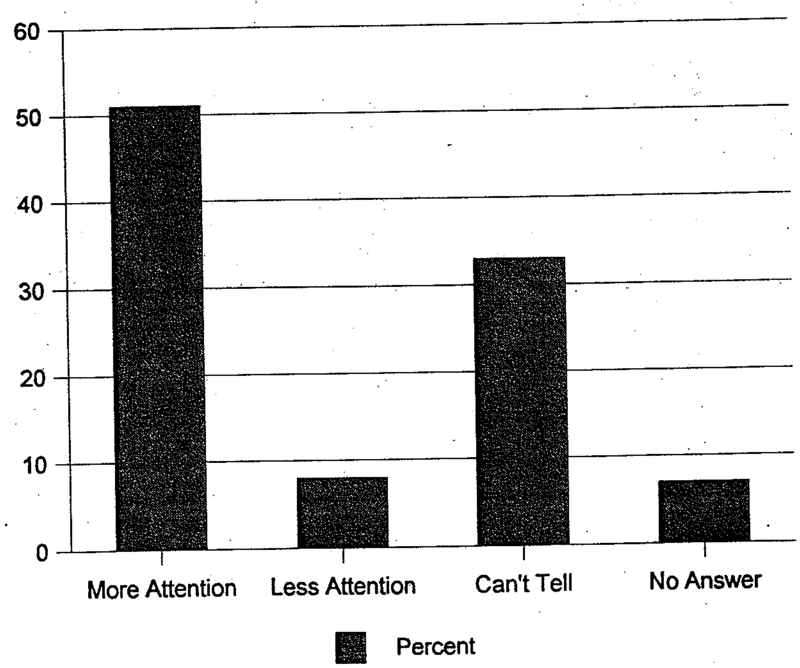

Figure 3. Teachers' perception of whether students pay more or less attention to text combined with graphical displays.

Teachers' Training in Chart Use

One-half (50.6%) of the respondents had some formal instruction about teaching students how to use charts. Instructors with a masters degree or greater were significantly more likely to have had formal training in interpreting or constructing graphs ($\chi^2 = 7.77, p < .01$).

Understand, Use or Construct?

More instructors suggested that it was more important for students, at the grade level they taught, to *understand* charts (48.5%), or **use** charts (42.4%) than it was for students to **construct** charts (28.7%). When teachers presented charts, 87% of the teachers reported they required students to interpret the information.

Teachers reported that students *constructed* graphs more frequently in Math (53.6%), and Science (35%), Social Studies (31.2%), English (15.9%), and History (14.9%). Foreign Language, Art and vocational areas reported a low incidence of student graph construction.

Academic Subjects Using Charts

The most frequent academic subjects in which charts were used for instruction were Math (52.2%), Social Studies (38.2%), Science (37.1%), English (27.5%), and History (19.6%). Areas where charts are not frequently used for instruction again include Foreign Language, Art, and vocational areas. See Figure 4.

When Should Students be Introduced to Charts?

Slightly less than half (48.5%) of the instructors reported students should be introduced to charts in Kindergarten. A lesser percentage (39.2%) of teachers would introduce children to charts in the first through third grades.

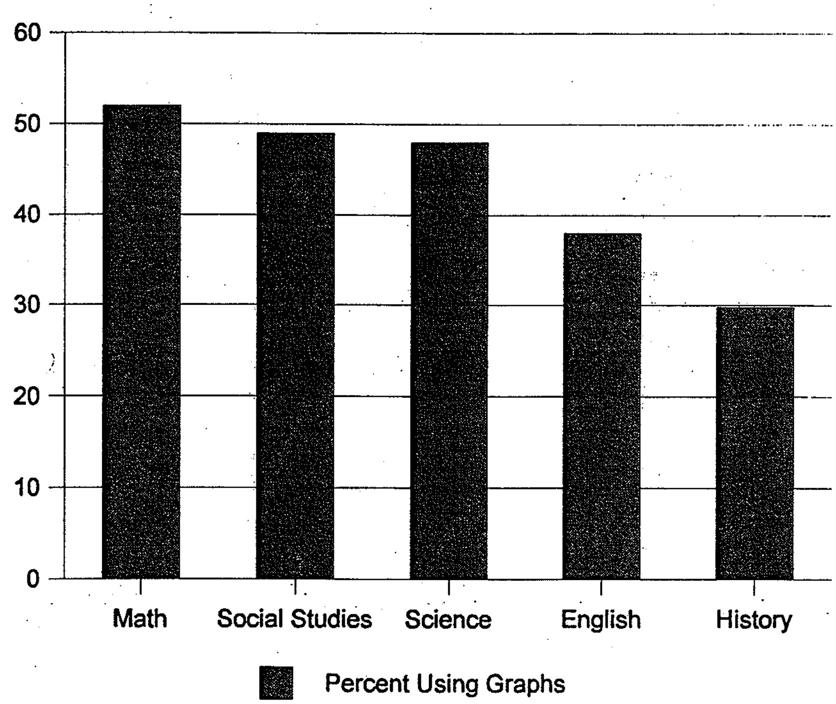

Figure 4. Use of graphical displays by academic subject.

How Do Teachers Teach Students to Read and Construct Charts?

Teachers were also asked to **describe** how they teach graphs. Of those responding, 25.6% mentioned using examples that related to their students and their daily lives. Other commonly mentioned methods included students constructing their own charts (24.8%), demonstration of charts (10.7%), and modeling (9.9%). Other methods described included using questions, discussion, and visualization.

Some responses suggested a clever use of the charting process. One example is shown in the following quotation from an elementary school teacher.

> M & M charting is a favorite of mine. Charting for the colors and also to determine more, less, most and least. Then the best part, they get to eat the M & Ms. This is a charting experience my students love to construct and one they also do at any holiday. I use the same principle as above using holiday candy in charting similar shapes.

Another inventive (and less caloric) approach to teaching the charting process was reported by an instructor who emphasized the motivational component of relevance.

> I had my math kids make a bar chart using information on the class (i.e., how they breakfasted, showered, petted a dog, watched TV, etc.) Then as a class we changed the bar chart to a picture chart, line chart, pie chart, and any other kind we tried to learn. They enjoyed tallying the data and interpreting it because it was about them. It was a very gratifying experience.

Discussion

A major trend reported in this study was that most instruction in graphical display use occurs in kindergarten and elementary schools. Given the more active nature of instruction at that level, it is not surprising that the attempt to make data more concrete is more common. It may be inferred from the data that many teachers think instruction in and use of graphical displays is less important past that point because older students have more well developed reading skills. The data presented in this study indicate that use of graphical displays drops to almost half in junior and senior high schools. Similarly, the use of any learning strategy to understand graphical displays declines as grade level increases. The corollary here is that referential connections (links between verbal and nonverbal symbolic systems) are assumed by teachers to be increasingly unimportant as students progress in school. This assumption contradicts recent psychological theories especially those of dual-coding (Paivio, 1986a), conjoint retention (Robinson, Katayama, Fan, 1996), and the contiguity effect (Mayer & Gallini, 1990).

According to dual-coding theory, activating an imagery system (such as graphs) can unify multiple objects into an integrated image (Clark & Paivio, 1991). Such an integration can facilitate memory for textbooks and other school materials. Paivio (1971, 1986) holds that there are three variables which increase the probability of imagery processing. These are: (1) instructions and related context effects, (2) concreteness, and (3) individual differences of learners. Consider these variables in relation to the findings of the present study. First, Paivio and his associates assert that students are more likely to generate mental images if instructed to do so than left to their own devices. The present study would suggest that as students progress through school and increase the use of verbal systems they receive instructions to use visual systems such as graphs less often (see Figure 1). The second determinant of imagery processing is concreteness or imagery value. This study found that graphs are being used most often in the highly quantitative areas such as Mathematics and Science. Graphs could also be employed for a variety of purposes in subject areas such as History including categorization and sorting, comparison and contrast, similarities and trends, summarization, and so forth. Graphs are a way of emphasizing concrete phenomena over the abstract. The implications of Paivio's third determinant, individual differences, are also pertinent. According to Clark and Paivio (1991), students who have trouble using image systems may fail to remember texts that benefit from imaging, may not understand geography of other spatial facts in a concrete fashion, and may do poorly in other areas such as visualizing steps of geometric proofs or spelling difficult words (p. 157). In this light, the sharp decline in employing graphical displays in instructional activities after elementary school seems foolish.

The data also suggest that bar charts are used much more frequently than other forms of graphical displays. There has long been evidence in the literature that bar charts are effective for comparisons (Croxton & Stein, 1932) and legibility (Culbertson & Powers, 1959). The heavy use of this type of chart in an age when other forms of graphical displays are readily available and may be more appropriate may be related to the limited use of graphs and charts in the formal academic and inservice training of junior and senior high school teachers. Approximately one-half of all of the teachers in this survey received no formal training in how to use graphical displays in their instructional activities. This would appear to be a major factor regarding teachers' lack of use or misuse of graphical displays in teaching. On the positive side, this survey suggests that formal training in interpreting or constructing graphical displays is significantly higher when teachers have attained a graduate degree.

One of the most common uses of graphical displays is with text. This use continues beyond school settings and is a mainstay in many adult communications (e.g., quarterly reports or newspaper accounts). The assumption is that graphs help to emphasize or explain more abstract data presented in a textual form. Noteworthy, therefore, is that only about half the teachers surveyed suggested that students paid more attention to text combined with charts. One explanation for this teacher perception may be that graphical displays are taught much more frequently in subjects that use less text (e.g., Mathematics) than in subjects that are heavily dependent on text (e.g., History). By contrast, a growing number of research studies suggest that student learning is improved by presenting text and graphical displays together (Glenberg & Langston, 1992; Purnell & Soloman, 1991; Waddil, McDaniel, & Einstein, 1988).

Some researchers suggest that constructing graphs (as opposed to reading or interpreting them) may increase the learning of graphic representations (Brasell, 1987). Data collected in this survey suggest that most teachers place less emphasis on constructing graphical displays. Most of the teachers who do encourage their students were at the elementary level. The exception to this trend was in mathematics, where newer technologies such as graphing calculators and computer programs may be making the process easier at junior and senior high school grades (Linn, Layman, & Nachmias, 1987).

Implications

Colleges of Education, teacher continuing education programs, and inservice administrators would do well to incorporate formal training experiences in using graphical displays. That one-half of the teachers in this survey reported receiving no training at all in the instructional use of graphical displays reflects poorly on these programs. In the upper grade levels, where graphical displays use is at its lowest level, such promising techniques as real-time graphing (Brasell, 1987) have great promise for allowing students the opportunity to construct graphical displays and aid in their comprehension of data.

Only about half of the teachers in this study reported that students paid more attention to graphs combined with text. If this perception is true, it could be because the instructional materials have failed to make a "visual argument" (MacDonald-Ross, 1978). Frequently, the cause of this is the failure by courseware developers to reach a harmony between graphic and instructional design principles. Graphical displays should embody information in a way that delivers a message to learners. When used with text they should use a design layout that tracks the graphical display to textual content.

Well-researched principles combine the best of both instructional and graphical design. For example, how information is "chunked" or summarized (Miller, 1956), influences the amount of human memory required for the display (Simcox 1983a; 1983b). Discriminating color use (Waller, Lefrere, & MacDonald-Ross, 1982) and related typographic cuing (Misanchuk, 1992) guide the learner's exploration of printed materials. Simplicity (Head & Moore, 1989), learner preference (Fisher, Dempsey, & Marousky, 1997), and graphical integrity (Tufte, 1983) may be used intentionally to clarify, gain attention, and promote retention.

Students should be encouraged to construct graphs more frequently in text-laden academic subjects. For instance, this survey indicated that graph construction in History is especially low. Graphing could certainly be a valuable tool for students to make historical trends more concrete or for a variety of other explanatory or exploratory purposes. Cross-curricula teacher training innovations modeled after the successful "Writing Across the Curriculum" program (Johnson, 1989), could assist instructors in incorporating graphical display activities into instruction. Allowing students to work in groups may encourage more successful graphical display construction (Jackson, Berger, & Edwards, 1989).

Educational researchers and instructional designers would be wise to study those teachers who are using clever strategies to teach students to construct or interpret graphical displays. Although there are a limited number of "how-to" articles available in teacher-oriented magazines (Paine, 1983), insufficient information is available to teacher educators about the effectiveness of imaginative methods which incorporate graphical displays into curricula. Anecdotal information in this survey found that some teachers have initiated or adopted some interesting techniques for making graphical displays more relevant to students' learning processes. By studying the instructional methods used by these teacher-innovators, qualitative researchers, in particular, have an unusually rich opportunity to contribute to the literature on using and understanding graphical displays of the complex information that permeates our lives.

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