DOCUMENT RESUME

ED 240 768 EC 161 831

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TITLE The Development of Fundamental Skills in Tactile Graph Interpretation: A Program for Braille Readers. Final Report.
INSTITUTION American Printing House for the Blind, Louisville, Ky.
SPONS AGENCY Office of Special Education and Rehabilitative Services (ED), Washington, DC.
PUB DATE Sep 83
GRANT G008001878
NOTE 34p.
PUB TYPE Reports - Evaluative/Feasibility (142)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Blindness; *Braille; Elementary Secondary Education; *Graphs; *Tactile Adaptation

ABSTRACT

The report describes the development and evaluation of an instructional program in tangible graph interpretation for braille readers. Because graphs frequently appear in textbooks and in other printed sources, lack of appropriate translation for blind persons can be a significant educational obstacle. Based on anlyses of typical graph reading tasks, skills and concepts fundamental to the graph reading process were identified and then incorporated into a logically sequenced instructional program. A high priority was given to the application of relevant research findings in the areas of display design and skills training. The effectiveness of the program was assessed using 60 braille readers in grades 5-10. The results indicated that substantial gains in graph literacy could be realized with the program in a relatively short time. (Author/CL)

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ED240768

Final Report

Project No. 023CH10324
Grant No. G00B00187B

The Development of Fundamental Skills in Tactile Graph Interpretation: A Program for Braille Readers

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September 1983

The research reported herein was performed pursuant to a grant with the Office of Special Education and Rehabilitative Services, U. S. Department of Education. Contractors undertaking such projects under Government Sponsorship are encouraged to express freely their professional judgment in the conduct of the project. Points of view or opinions stated do not, therefore, necessarily represent official Department of Education position or policy.

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Abstract

Recognition of the importance of graphic displays as communication devices has led to increased efforts in the past decade to convert such displays into a form compatible with the perceptual capabilities of blind persons. This has resulted in the investigation of a number of concerns, including methods of production, display design, and display-reading skills. One area, graphic interpretation training, has, however, received a paucity of attention. This is particularly evident for the frequently encountered category of displays known as graphs. This paper describes an effort to develop an instructional program in tangible graph interpretation for braille readers. Based on analyses of typical graph reading tasks, skills and concepts fundamental to the graph reading process were identified and then incorporated into a logically sequenced instructional program. A high priority was given to the application of relevant research findings in the areas of display design and skills training. The effectiveness of the program was assessed using 60 braille readers in grades 5-10. The results of this evaluation indicated that substantial gains in graph literacy could be realized with the program in a relatively short amount of time.

Introduction

Graphic displays are useful tools for communicating certain types of information which cannot be easily or efficiently represented in verbal form. Recognition of this capability is reflected in the growing usage of nonverbal material, a trend that is expected to continue into the foreseeable future (Kirchner, 1979). There simply does not seem to be a more effective vehicle for conveying such information as the spatial relationships of the components of a map, the schematic representation of an object in a diagram, or the relationships between variables in a graph. Any person, regardless of visual status, is placed at a disadvantage if not provided access to the wealth of information available in graphic displays.

Recognition of this fact in the field of the blind has led to increased efforts in the last decade to convert visual graphics into tangible form. This has resulted in the investigation of a number of concerns, including methods of production (Barth, 1982; Gill, 1973b; James, 1975; Bentzen & Peck, 1979; Berla' & Butterfield, 1977a; Berla' & Murr, 1975a; Lederman & Campbell, 1982; Lederman & Kinch, 1979; Nolan & Morris, 1971; Schiff, Kaufer, & Mosak, 1966; Wiedel & Groves, 1969), and display-reading skills (Berla', 1973; Berla', 1981; Berla' & Butterfield, 1977b; Berla', Butterfield, & Murr, 1976). This last category has primarily involved the determination of, or training in, specific systematic skills for effective display examination. Projects concerned with the more global aspect of graphic interpretation training have been more scarce. In the area of map interpretation, some training programs have been developed: Maps in the Classroom I (Franks, 1982); Maps in the Classroom II (Franks, 1974); Landform Models (Franks & Baird, 1971a; Franks & Baird, 1971b); Simplified Continental Relief Maps--Cassette Program (Franks, 1979). Although not an actual program, a very useful set of guidelines has been described by Bentzen (1980) for the systematic development of mobility-map interpretation. No systematic training programs are available for other types of graphic displays.

Tangible graphs fall into this neglected category, despite the fact that they represent a significant proportion of the graphics that appear in print. Their importance as a communications tool is attested to by the frequency with which they appear in textbooks and other educational media, in such diverse subject areas as mathematics, social studies, physical sciences, biological sciences, and business. They are increasingly encountered in newspapers and magazines. Interestingly, in a position paper on basic mathematical skills (1977), the National Council of Supervisors of Mathematics identified the reading and interpretation of graphs as one of 10 basic skills areas that need to be emphasized in mathematics education. The development of graph skills was also identified as a high priority by six prominent mathematics educators in a needs meeting conducted by the American Printing House for the Blind (1979). Graph literacy is thus expected of any educated person and is in fact tested in standardized educational measures such as the Stanford Achievement Test, the California Achievement Tests, the Scholastic Aptitude Test (SAT), and the American College Testing Program (ACT). The college-bound or career-bound blind person will be particularly handicapped by an inability to read graphs. A review of the literature on tangible graphic displays by Berla' (1982) noted both the lack of research and development and the need for instructional materials in the area of graphs. This conclusion was echoed in a Workshop on Tangible Graphic Displays held in 1979 at the University of Louisville (Schiff, 1982). Seventeen blind participants from a variety of backgrounds reached a general consensus that the use and interpretation of graphic displays, including graphs, have not received the attention they deserve. They recommended that intensive training materials be introduced at an early point in the education of visually handicapped students. As Peter Selby (1976) has pointed out, "With the growing use of graphs and tables to summarize data from every branch of science, industry, business, and government, all of us need to be familiar with their purpose and use" (p. 1).

Program Development

"The Development of Fundamental Skills in Tactile Graph Interpretation: A Program for Braille Readers" represents an effort to bridge this gap in a blind student's education. In developing this program, now entitled Tangible Graphs, the following activities were carried out sequentially: (a) the identification of fundamental graph reading skills, concepts, and operations, (b) the incorporation of these skills, concepts, and operations into a graph test, (c) the development of an instructional program, (d) field evaluation, and (e) revision and production.

The first activity laid the foundation for the entire project. Skills, concepts, and operations fundamental to the graph reading process were derived by rigourously analyzing the explicit (what information is being sought) and implicit (what skills, concepts, and operations are assumed) tasks required by the graphs which appear in textbooks, graph instructional programs for the sighted, and standardized academic tests. The types of graphs commonly used and the grade level at which each type is typically encountered were also identified during this search and analysis phase of the project.

Forty textbooks in the areas of mathematics, social studies, science, and business from grades 2-12 were scrutinized. Those chosen were considered representative of the textbooks commonly used in the educational system. All of them were, in fact, selected by the Editorial Department of the American Printing House for the Blind for transcription into braille after a careful review process. The graph content of two standardized tests was also analyzed. These were the Stanford Achievement Tests (grades 2.5-12) and the KeyMath Diagnostic Test (preschool to grade 6). In addition, 14 print graph instructional programs were identified and their contents examined in detail. These task analyses resulted in the identification of approximately 70 skills, concepts, and operations (see Appendix A) that are needed to interpret the information contained in four main types of graphs: pictographs, bar graphs, line graphs, and circle graphs.

A criterion-referenced, multiple-choice test was then developed for assessing a student's attainment of these skills and concepts. The test has a twofold purpose: (a) to serve as a diagnostic instrument for determining a student's level of mastery prior to entry into the program (where to start) and subsequent to instruction (further emphasis, remediation) and (b) to serve as an assessment instrument in the program evaluation phase of the project. The list of skills and concepts and the test itself were critically reviewed and revised by a committee of consultants composed of one curriculum specialist in mathematics instruction and six mathematics and social studies teachers from residential and public school programs for the blind (see Appendix B).

In constructing the instructional text itself, the objective was to develop the fundamental graph reading skills and concepts in a systematic, logical sequence of increasing difficulty or complexity. The approach taken was basically an amalgamation of two skills training techniques, the part-continuous method (Holding, 1965) and the linear programming method. In the part-continuous approach to training, the parts making up a skill are presented to the learner one at a time. As each new part is presented, it is practiced in conjunction with previously learned parts until the entire skill is built up. The linear programming method follows a similar strategy and further specifies that the sequential steps used in developing a skill or concept be small in size. This is to insure that each step is understood by the learner, thus avoiding frustration and providing positive reinforcement. Such systematic approaches were found to be lacking in existing graph instructional programs for the sighted. These programs typically used large or extremely erratic step sizes and in many cases did not even attempt to develop a logical progression of complexity either within graph types (for example, presenting a multiple line graph prior to a single line graph) or between graph types (for example, presenting line graphs prior to bar graphs or pictographs). In addition, all of these programs made assumptions about prior knowledge of various skills and concepts, although these assumptions differed between programs.

Based on the fact that blind students characteristically exhibit poor tactual display-reading skills (Berla', Butterfield, & Murr, 1976; Nolan & Morris, 1971) and generally receive little instruction in graphic interpretation (Berla', 1982), it was decided that the present program should begin, as it were, at the beginning. Consequently the first part of the program, or approximately 25% of the 164 page text, is devoted to the development of skills and concepts that are prerequisites to the effective interpretation of any tangible graphic display. Thus, the text begins with an examination of points, lines, and areal patterns, the building blocks of all graphic displays. Distinctive features of symbols both within and between these three symbol classes are discussed; perceptual training is given in the form of pair comparison and matching tasks. The symbol sets are presented in both paper and plastic (Brailon) media to acquaint the student with the characteristics of each. Both media are used throughout the program, in approximately equal proportions.

The program then proceeds to a discussion of directional and locational referents, both with respect to the layout of the page itself and the interrelationships of elements appearing on a page. This is followed by training in the skills of systematically scanning a display (Berla', 1981; Berla' & Murr, 1974) and of tracking lines by the two-finger method (Berla', 1973). These skills are practiced on displays of increasing complexity, from lines in isolation to intersecting lines to lines embedded in points and areal patterns. Much of the work is couched in the form of games to elevate student interest. Concepts are then presented which are essential to an understanding of the interrelationships of lines, the most frequently used class of symbols in graphs. These include such concepts as horizontal, vertical, diagonal, parallel, perpendicular, intersecting, longer, and higher.

At this point the program focuses on concepts more directly related to graphs, beginning with an exposition on number lines. Pictographs are presented next and are then used to develop an understanding of simple bar graphs.

After exploring the distinctive features common to all graphs (title, axes, axes labels), the idea that a given location in two dimensional space can be specified by means of a coordinate reference system is introduced. This proceeds from a discussion of rows and columns (layout of desks in classroom; tables) to the layout of streets in a map to the grids used in graphs. Point location exercises follow, again in game form.

Bar graphs are then used to develop an understanding of simple line graphs. The interpretation of increasing and decreasing line trends is particularly emphasized in this section. Following a discussion of circle graphs, the program returns to line graphs to deal with more complex concepts such as slope and the presentation of multiple data curves in a single display. Discussions and exercises in this concluding section of the program focus primarily on the process of comparing two or more data curves.

Throughout the program, an active student role is fostered, not only in examining and interpreting the numerous displays presented in the text, but also in graphing data generated by the student himself. Materials are included to facilitate the graph construction process, and suggestions for relevant activities are included in a Teacher's Guide. This guide, which contains a complete print version of the program, also presents information pertinent to the development of systematic display-reading skills and strategies (for example, a systematic strategy for determining the coordinate values of a graph point using the index fingers of both hands). As Berla' (1972) and Berla', Butterfield, & Murr (1976) discovered, the single most important factor distinguishing effective from ineffective display reading is the use of some type of systematic approach.

All of the tangible displays in the program were designed and constructed for maximum readability based on information obtained in a number of investigations: structural characteristics of symbols within each symbol class (see reviews by Bentzen, 1980, and Nolan & Morris, 1971), differences in elevation between and within symbol classes (Gill, 1973a; Nolan & Morris, 1971; Schiff & Isikow, 1966), discriminable line widths (Berla' & Murr, 1975b), sizes of point and areal symbols (Morris & Nolan, 1963; Nolan & Morris, 1971), structural characteristics of intersecting lines and their point of intersection (Easton & Bentzen, 1980; Schiff & Levi, 1966), trackability and memory representations of single versus double lines (Easton & Bentzen, 1980), minimum symbol separation (Bentzen, 1980; Nolan & Morris, 1971), stimulus redundancy in histograms (Schiff & Isikow, 1966), overall display size (Armstrong, 1973), format for keys and labels (Schiff, 1982).

One display feature in particular has proved to be troublesome in tangible graph reading, namely, the grid background (coordinate reference system). Barth (1983a) found that it took blind students in grades 4-12 144% more time to track lines embedded in a raised grid than ones displayed against a smooth background. This occurred despite the fact that the tracked lines and grid line were highly discriminable, different in elevation, and separated by a distance of 3 mm (.12 inch). All grade levels were similarly affected. In an attempt to alleviate this problem, Barth (1983b) examined a new type of grid composed of incised lines. Compared to a raised grid, the incised grid facilitated performance on three graph reading tasks: (a) line tracking,

(b) location of minimum and maximum data curve peaks, (c) location of point symbols. Performances on these tasks with the incised grid were in fact similar to those achieved with no grid present. Furthermore, the incised grid did not impair the students' ability to locate accurately the x and y coordinate values of a graph point. Performances on this task were comparable to those attained with the raised grid. Consequently, the incised grid format was used in many of the graphs included in the program. Raised grids were, however, also used, since students will continue to encounter this format. A no grid format was used when the precise location of points in the graph space did not represent an important purpose of the graph (Schiff, 1982).

As was indicated previously, both paper and plastic media are used throughout the program. The plastic displays are thermoform copies of foil masters produced with the Tactile Graphics Kit (Barth, 1982). This kit of tools and materials has the capability of embossing a foil master with seven linear symbols, seven point symbols, and four areal patterns, all of which have met stringent criteria of legibility. The paper displays were produced by a process which involves: (a) the embossing of an image in a folded zinc plate to form a male-female die set, and (b) the impressing of the image in heavy braille paper by sandwiching the paper between the plates and applying pressure with a platen press. A new mechanical embossing system is currently under development and will be used to produce the metal plate masters for the final production version of the program. In comparison to the current method of plate embossing (largely a hand tool operation), the new system will be superior in terms of the quantity (displays embossed per unit of time), quality (tactual clarity), versatility (symbol variety), and consistency of its output.

The last major phase of the project involved a field evaluation of the program. One group of braille reading students from grades 5-10 was designated an experimental group and given instruction in the graph program. No instruction was given to another group of braille readers in grades 5-10, who thus served as a control against which the efficacy of the instructional program could be determined. The program package used by the experimental group consisted of the following items: (a) student copy of Tangible Graphs program--164 pages (in three volumes) of braille text and raised graphic displays, (b) materials for student construction of tangible graphs--12 X 12 inch (30 X 30 cm) corkboard, pins, rubber bands (various sizes), and five sets of embossed graph sheets (three sizes of grid grain for the construction of bar graphs and line graphs, two sets of circles with different degrees marked off along the circumference for the construction of pie graphs), (c) test of graph skills, concepts, and operations (three volumes)--64 multiple-choice questions involving raised graphic displays (with braille answer sheets), (d) Stokes Place Holder aid--lightweight metal sheet with magnet for place keeping on a brailled page (also provides rigid surface upon which to examine tangible graphic displays), and (e) Teacher's Guide--print version of Tangible Graphs program (including, in addition, instructional information for the teacher).

Field Evaluation

Method

Subjects

All 60 of the students who participated in the field evaluation used braille as their primary mode of reading. No student had less than 3 years experience in reading braille. Half of the students were from grades 5-7, half from grades 8-10. In each of these grade groupings, 60% were enrolled in residential schools for the blind, 40% in public school programs. None of these students had previously received any formal, systematic instruction in tangible graph interpretation. Demographic information by grade grouping and treatment condition is contained in Table 1.

Table 1

Demographic Data

	Grades 5-7		Grades 8-10	
	Experimental	Control	Experimental	Control
Male-Female	7-8	9-6	10-5	7-8
Age	*M* = 12.3 *SD* = 1.1	*M* = 12.8 *SD* = 1.4	*M* = 15.3 *SD* = 1.4	*M* = 15.5 *SD* = 1.1
Grade placement	*M* = 6.3 *SD* = .7	*M* = 6.3 *SD* = .8	*M* = 9.3 *SD* = .8	*M* = 9.3 *SD* = .7

Field Evaluators

Teachers of the blind throughout North America served as field evaluators of the instructional program and/or the graph test (see Appendix C). Participating areas included Arkansas, California, Connecticut, Florida, Illinois, Missouri, North Carolina, Utah, Washington, and Ontario, Canada. Of the 35 teachers involved in the study, 13 were from residential school programs and 22 from public school, itinerant programs. The primary teaching responsibilities of these individuals varied considerably, encompassing such subject areas as braille reading, music, mathematics, language arts, social studies, science, typing, and industrial arts. Twenty of the teachers worked with the students in the experimental group, and 15 worked with those in the control group.

Procedure

In Fall 1982, the graph instructional program and the graph test were sent to the teachers in the experimental group. The teachers in the control group received only the graph test. A complete program and/or test was sent for each student participating in the study.

At the beginning of the evaluation period, all 60 students were administered the 64-item, multiple-choice graph test. Using a set of sample test items, the teacher first familiarized the student with the test format and the proper marking of the answer sheet (see Appendix D for test administration instructions). The student then proceeded with the test proper. No time limit was imposed. Feedback of results was not provided. Immediately after testing, the completed answer sheets were mailed back to the American Printing House for the Blind for scoring by personnel in the Department of Educational Research.

This initial, baseline testing was then followed by a period of instruction in the graph program for the 30 students in the experimental group. The 30 students in the control group received no graph instruction during this period. The duration of the instructional period and the actual amount of instruction given per week varied from student to student. This was due to (a) differences in ability and ease of learning between students, and (b) the workload (and consequent time constraints) of individual teachers and/or students. All teachers were strongly urged, however, to complete the entire instructional program with each student. In actuality, 23 (77%) of the students did complete the program. The amount of the instructional text covered by the remaining seven students ranged from 58% to 85%.

All 60 students then completed their participation in the field evaluation with a second administration of the graph test. The administrations of the first and second testings were separated by an average interval of 10.2 weeks (SD = 2.4) for the experimental groups and 10.6 weeks (SD = 1.8) for the control group. The average amount of time spent in instructing students in the experimental group came to approximately 1.7 hours/week, with a range extending from less than 1 hour/week to 4.5 hours/week.

The final responsibility of the teachers in both groups was to complete an evaluation questionnaire. For the teachers in the experimental group, the questionnaire involved a comprehensive evaluation of the design and content of both the instructional program and the graph test. Additional feedback was obtained from critiques made by these teachers as they progressed through the program during the instructional period. These comments, criticisms, and suggestions for improvement were recorded directly in the Teacher's Guide by each teacher. A questionnaire involving the graph test was the only feedback obtained from the teachers in the control group. Upon return of these materials and the results from the second testing, an honorarium of $150.00 was issued to the teachers in the experimental group and $40.00 to those in the control group for their participation in the field evaluation.

Results

Graph Test

Test reliability. The reliability of the graph test was examined by calculating a Pearson Product Moment correlation coefficient on the pretest-posttest data of the 30 students in the control group. The resulting coefficient, r (28) = .94, $p < .001$, indicated a high degree of consistency between the scores obtained by the same individuals on the two separate occasions, thus making it extremely improbable that individual differences in test scores are attributable to factors irrelevant to the knowledge and skills under consideration.

Test data--overall. The data from the two test administrations consisted of the percentage of test items answered correctly by each of the 60 students. The students in the control group received a mean score of 58% on the pretest and 58% on the posttest, for no gain. In contrast, the students in the experimental group received mean scores of 56% and 84%, for an average gain of 28% from pretest to posttest. The facilitative effect of the instructional program on graph reading performance, as evidenced by this difference between the groups, was found to be highly significant by a 2 (grade grouping) X 2 (experimental treatment) Analysis of Covariance (ANCOVA), $F\ (1,55) = 232.68,\ p < .001$ (see Table 2). The ANCOVA technique is the preferred method for analyzing data from a pretest-posttest control group design (Huck and McLean, 1975). Using the pretest scores as a covariate, ANCOVA statistically controls for initial differences between groups, thus providing a more powerful test of the experimental treatment, in this case, graph instruction.

Table 2

Analysis of Covariance for Pretest-Posttest Data

Source	SS	df	MS	F
Covariate	2679.30	1	2679.30	140.93***
Grade grouping (G)	.023	1	.023	< 1
Instruction (I)	4423.71	1	4423.71	232.68***
G X I	146.86	1	146.86	7.72**
Explained	7255.68	4	1813.92	
Residual	1045.66	55	19.01	
Total	8301.33	59	140.70	

**$p < .01$
***$p < .001$

Further ANCOVA analyses indicated a significant interaction between the treatment and grade grouping factors, $F\ (1,55) = 7.72,\ p < .01$. While the experimental students in grades 5-7 increased their scores from a mean of 48% on the pretest to a mean of 80% on the posttest, for a gain of 32%, their counterparts in grades 7-10 only increased theirs from 64% to 87%, for a gain of 23%. This difference was responsible for the interaction effect, since the control students in both grade groupings showed essentially equal changes in performance from pretest to posttest: 53% to 52% for grades 5-7; 63% to 65% for grades 8-10. This comparability of control group gains undoubtedly accounts for the lack of a main effect due to grade grouping ($F < 1$). For a summary of the test data, see Table 3.

Table 3

Graph Test: Mean Percentage Correct Responses
(standard deviations in parentheses)

	Experimental group		Control group	
Grade grouping	Pretest	Posttest	Pretest	Posttest
5-7	48 (10)	80 (11)	53 (15)	52 (16)
8-10	64 (12)	87 (10)	63 (14)	65 (13)
5-10	56 (14)	84 (11)	58 (15)	58 (16)

Test data--subscores. Additional information was gleaned from the test data by conducting separate analyses on two main subdivisions of the graph test. Questions 1-24 of the test were concerned primarily with more general display reading skills and concepts. Questions 25-64 primarily involved skills and concepts specifically related to the reading of graphs. On the first subdivision of the test, the experimental students in grades 5-7 improved their scores from a mean of 70% on the pretest to 85% on the posttest. Their counterparts in the control group improved from 70% to 73%. The experimental students in grades 8-10 improved from 84% to 94%. A similar gain was made by the control students in grades 8-10, from 77% to 86%. Overall, the experimental group improved by a mean of 12% from pretest to posttest (78% to 90%), the control group by 7% (73% to 80%). An ANCOVA revealed a significant effect due to instruction, $F\ (1,55) = 14.61$, $p < .01$. In addition, the magnitude of the instructional effect was again found to depend on grade grouping, $F\ (1,55) = 6.37$, $p < .02$. For this subdivision, of the test, the instructional program had a greater effect on the performance of the students in grades 5-7.

On the second subdivision of the test, the experimental students in grades 5-7 gained 41% from pretest to posttest (35% to 76%). The control students in grades 5-7 lost 4% (43% to 39%). In comparison, the experimental students in grades 8-10 improved by 33% (51% to 84%), while their counterparts in the control group decrased by 3% (55% to 52%). Overall, the experimental group's scores increased by 37% (43% to 80%). The control group's decreased by 4% (49% to 45%). The difference in performance between these two groups was found to be highly significant by an ANCOVA, $F\ (1,55) = 236.75$, $p < .001$. The interaction between grade grouping and treatment, however, was not sifnificant, $F\ (1,55) = 3.33$, $p > .05$, indicating a comparable facilitative effect of instruction for the students in both grade groupings. For a summary of the data from the test subdivisions, see Table 4.

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Table 4

Graph Test Subdivisions--Mean Percentage Correct Responses
(standard deviations in parentheses)

	Grade grouping	Experimental group Pretest	Experimental group Posttest	Control group Pretest	Control group Posttest
Questions 1-24 (general)	5-7	70 (13)	85 (10)	70 (13)	73 (14)
	8-10	84 (11)	94 (07)	77 (15)	86 (13)
	5-10	78 (14)	90 (09)	73 (09)	80 (09)
Questions 25-64 (graph-related)	5-7	35 (13)	76 (13)	43 (19)	39 (20)
	8-10	51 (15)	84 (12)	55 (15)	52 (15)
	5-10	43 (16)	80 (13)	49 (18)	45 (19)

Questionnaire

Graph test. All 35 teachers participating in the field evaluation responded to questions concerning the graph test. The response to each question involved the placing of a check mark in one of two boxes, labelled "YES" and "NO." For simplicity, the results for each question are reported as percentages (see Table 5).

Table 5

Questionnaire Responses--Graph Test

Question	YES	NO	No response
1. Do you think this test realistically assesses a student's grasp of graph reading skills and concepts?	100%	0%	0%
2. Were all of the skills and concepts covered in the test worth including?	97%	3%	0%
3. Were all the important skills and concepts tested?	83%	6%	11%
4. Was the wording of the questions acceptable?	91%	6%	3%
5. Was the format of the test acceptable?	88%	6%	6%

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Table 6 (continued)

Question	YES	NO	No response
22. Was the method of binding acceptable?	100%	0%	0%
23. Did your student(s) use the Stokes Place Holder aid?	50%	50%	0%
24. Was the Stokes Place Holder aid useful?	40%	50%	10%
25. Do you think it would be worthwhile to make an adaptation of this program for low vision students?	95%	5%	0%

In addition to responding to the questions in Table 6, the teachers were asked to indicate their satisfaction or dissatisfaction with the development of each of the skills and concepts covered in the program. In general, the degree of satisfaction was very high. The greatest dissatisfaction occurred for the handling of "interpolation" and "range," and even these were only a concern for 20% of the teachers.

Teacher's Guide. The 20 teachers involved with the experimental group also answered several questions on the program guidebook. Their responses are summarized in Table 7.

Table 7

Questionnaire--Teacher's Guide

Question	YES	NO	No response
1. Were the style and size of print used in the Teacher's Guide acceptable?	95%	0%	5%
2. Were the graphic displays in the Teacher's Guide acceptable?	90%	0%	10%
3. Was it easy to refer back and forth between the Teacher's Guide and the braille text?	85%	5%	10%
4. Did the Teacher Notes provide useful information?	95%	0%	5%
5. Were additional Teacher Notes needed?	20%	75%	5%

Item analyses. The percentage of experimental students giving a correct response was calculated for each question of the graph test (second administration). This was done to pinpoint areas in need of further development or revision. Overall, there were no extremely low percentages. The lowest

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percentage obtained was, in fact, 57%, which occurred for two of the questions. These questions were concerned with the location of the horizontal axis and the location of a graph point given its coordinate values. The students in grades 5-7 were largely responsible for these low percentages.

Eight questions accounted for percentages in the 60-70% range. These questions were concerned with the following skills and concepts: perpendicularity, intervals on a number line, interpreting differences between bar pairs in a double bar graph, determining the x coordinate of a graphed point, determining the coordinate values of a point on a data curve, determining fractional values of sections of a circle, using a conversion graph, and determining the y value associated with a particular x value in a line graph. All other questions were answered correctly by more than 70% of the students.

Discussion

Two groups of blind students from grades 5-10 participated in a field evaluation of the Tangible Graphs program. One group received instruction in the program, while the other served as a control. Both groups were administered a test of graph skills, concepts, and operations at the beginning and end of the evaluation period. The results of this study indicate that substantial gains in graph reading performance can be achieved with Tangible Graphs in a relatively short amount of time.

The experimental students in grades 5-7 increased their test scores from an average of 48% on the pretest to 80% on the posttest. The experimental students in grades 8-10 increased theirs from 64% to 87%. The scores of the control students in both grade groupings remained essentially unchanged. Furthermore, if one considers only those test questions relating specifically to graph reading skills and concepts, as opposed to more general ones, an additional 9% increase in test scores was realized by the experimental students. While the absolute level of performance was higher for the students in grades 8-10 on both the pretest and posttest, the lack of a significant treatment by grade grouping interaction effect indicated a similar improvement on graph related material for both grade groupings. This was not the case for the test material that was concerned primarily with more general display reading skills and concepts. For this material, in addition to a significant overall effect of instruction, there was also a significant treatment by grade grouping interaction. This latter effect appears to have occurred for several reasons. First, the experimental students in grades 5-7 showed a greater improvement from pretest to posttest than those in grades 8-10 (15% versus 10%). Second, the control students in grades 8-10 improved as much as did their experimental counterparts, while the control students in grades 5-7 showed very little improvement. Why the control students in grades 8-10 improved while those in grades 5-7 did not is not clear. And, finally, it is possible that a ceiling effect was operating to limit the absolute amount of improvement for the experimental students in grades 8-10. With a mean score of 84% on the pretest these students had little room for improvement on general display-reading skills and concepts. Those in grades 5-7, starting with a mean score of 70%, had more to learn. It is possible that this ceiling effect also accounts for the significant treatment by grade grouping interaction found for the test as a whole. The experimental students in grades 8-10 began the study with considerably more graph reading knowledge than those in grades 5-7 (64% as compared to 48%). Overall, the students in grades 5-7 had more room to improve.

In retrospect, it would have been desirable to observe the effects of the program on an even younger sample of blind children, perhaps from grades 3 and 4. While the relatively high performance of the students in grades 5-7 on general display reading skills and concepts represents an encouraging finding, it limits the evaluation of the program's facilitation in this area. Because of cost considerations and time constraints, it was decided at the beginning of the project that the greatest amount of information could be obtained by concentrating on students who could be reasonably expected to complete the entire program within the time allowed. Since the reading difficulty of the program is approximately at the third grade level, it seems reasonable, however, to assume that younger students could benefit from the program, especially the first part, which is concerned with general display reading skills and concepts.

Besides the small, but significant, effect of this first part of the program on experimental group scores as a whole, additional evidence for its facilitative effect can be seen in the improvement achieved by individual students. Two experimental students from grades 5-7 are particularly noteworthy in this regard. Beginning the evaluation period with rather low scores of 58% on general display reading skills and concepts, both improved considerably by the posttest, receiving scores of 100% and 96%.

An exceptional amount of improvement was also achieved by several students on graph related skills and concepts. Three students from grades 5-7 improved by 60% on this part of the test. Three otners improved by 52%, 55%, and 58%. In grades 8-10, improvements by individuals were not quite as dramatic, the largest increase being 42%. However, as noted previously, the students in this group had less room to improve. Three of the 15 experimental students in grades 8-10 did, in fact, improve to the maximal extent possible, receiving perfect scores on this section of the posttest. Two others received a 95% on the postttest.

Considering both group outcomes and the performances of individual students, it is, therefore, clear that substantial gains in graph reading skills, concepts, and operations were realized by the students receiving instruction, relative to both their own pretest scores and to the scores obtained by the students in the control group. This is especially significant given the fact that (a) 23% of the students in the experimental group did not complete the program, and (b) the program was only taught for an average of 1 1/2 hours per week over a 10-week period. These limitations were largely due to time constraints. Several teachers suggested that two semesters (rather than one) would be more realistic for a thorough study of the program materials. In particular, they indicated the need for more time to do justice to the participatory exercises.

In addition to the performance data collected or each student, subjective feedback on both the program itself and the graph test was obtained from all of the teachers in the experimental group. The teachers in the control group provided feedback only on the graph test. In general, an extremely favorable response to the content and design of both the program and the graph test was found, indicating a high degree of face validity for both. Criticisms and suggestions for improvement were compiled and will be used, where deemed appropriate and feasible, to fine tune the program and test prior to production. None of the feedback received, however, indicated a need for major revisions in design or content.

Dissemination of information on the development and evaluation of the Tangible Graphs program has already been initiated. In March, 1983, the author gave a presentation entitled "Graph literacy: A neglected area" at the First International Symposium on Maps and Graphics for the Visually Handicapped, in Washington, D. C. The symposium papers in print form will be published in September, 1983, by the Association of American Geographers. They will also be published in braille and recorded forms by the National Library Service. In May, 1983, the author made a similar presentation in Atlanta, Georgia, at the American Foundation for the Blind's 35th research/practice seminar. In addition, it is expected that an article on Tangible Graphs will be submitted to an appropriate journal in the field of visual impairment. Advertisements of the program will, of course, be carried in the American Printing House for the Blind's catalog and brochures. Production of the program is expected to begin in the Winter of 1983-84, and should, therefore, be available for the 1984-1985 school year.

Summary

An instructional program was developed to facilitate blind students' understanding of graphs, an important and widely used informational tool. The program employs a carefully sequenced instructional approach, introducing fundamental graph reading skills and concepts in small steps, with each new step building upon previous ones. The student is thus brought along slowly from elementary skills such as tactual discrimination and line tracking to more advanced skills such as the interpretation of bar graphs and multiple line graphs. The program is replete with tangible graphic displays, all of which have been designed for easy readability. Accessory materials which allow the student to construct his or her own graphs are also included in the instructional package. After completing the program, the student should be able to interpret all four main types of graphs: pictograph, bar graph, line graph, and circle graph. It is also expected that the program will have some positive carryover effects on the reading of other types of graphic displays, such as maps and diagrams.

The effectiveness of the program was assessed using 60 braille readers in grades 5-10. The results of this evaluation indicated that substantial gains in graph literacy could be realized with the program in a relatively short amount of time. Subjective feedback indicated an enthusiastic response to the materials on the part of both teachers and students.

FOOTNOTE

1. The author wishes to acknowledge the contribution of Dr. Edward Berla' to the development of this instructional program.

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ERIC

Appendix A

Display Reading Skills, Concepts, and Operations

ERIC

General Skills, Concepts, and Operations

discrimination of symbol shapes, textures, and elevations

line tracking

straight, curved

below, above

right, left

on

inside, outside

length (short → long)

height (low → high)

vertical

horizontal

diagonal

parallel

perpendicular

intersection

intervals on a number line

number line: one to one correspondence between intervals and numerical progression

number line: one to many correspondence bteween intervals and numerical progression

definition of key

key interpretation

row (table)

column (table)

row, column intersections: cells (table)

acquiring information from a 2-variable table

Graph-related Skills, Concepts, and Operations

recognizing a pictograph format

recognizing a bar graph format

recognizing a line graph format

recognizing a circle graph format

locating and using a display title

horizontal or x-axis

vertical or y-axis

origin

grid (Cartesian coordinate reference system)

interpreting a pictograph (whole symbols)

interpreting a pictograph (fractional symbols)

interpreting a bar graph (determining relative heights or lengths of bars)

interpreting a bar graph (determining values for bar heights or lengths)

interpreting a double bar graph (determining differences between bar pairs in terms of within-pair bar differences)

over and up relative to the origin

determining upward or downward orientation of a line when scanning from left to right

determining coordinate value of a graph point (one axis)

determining coordinate value of a graph point (one axis) through interpolation

locating a graph point, given its coordinate values

determining coordinate values of a graph point (both axes)

determining highest and lowest points of a graphed line

determining relative areal sizes of sections of a circle

determining proportions for sections of a circle

interpreting a keyed circle graph

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trend (increasing, decreasing, quadratic, zero)

positive and negative slope

comparing slopes of two or more lines (absolute magnitude differences and rate of change differences)

range

determining the y-value associated with a given x-value (line graph)

determining the x-value associated with a given y-value (line graph)

interpreting a conversion graph

interpreting multiple-line graphs (point by point interline differences)

interpreting intersections in multiple-line graphs

extrapolating (line graph)

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Appendix B

Project Consultants

Mr. Anthony Evancic, Educational Supervisor, Western Pennsylvania School for Blind Children, Pittsburgh, Pennsylvania

Mrs. Dixie Howser, Mathematics Teacher, Kentucky School for the Blind, Louisville, Kentucky

Mrs. Karol Jump, Itinerant Teacher (Math, Social Studies, Science), Vista Unified School District; Vista, California

Mrs. Stephanie Richards, Mathematics Teacher, Indiana School for the Blind, Indianapolis, Indiana

Mrs. Margaret Ritchie, Mathematics Teacher and Vision Supervisor, Pasadena Unified School District, Pasadena, California

Dr. Charles Thompson, Associate Professor, Department of Early and Middle Childhood Education, University of Louisville, Louisville, Kentucky

Mr. Timothy Yerian, Itinerant Teacher (Social Studies, Science), Hamilton County Public Schools, Hamilton County, Ohio

Appendix C

Program Evaluators

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Ms. Suzi Bogom-Haselkorn, Rockville High School, Vernon, Connecticut

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Ms. Kathy Dempsey, Monterey County Office of Education, Special Education, Salinas, California

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Appendix D

Instructions for Test Administration

First Administration

Record the student's name (or identifying code) and grade level at the top of the answer sheet. Also record your name and school.

Say to the student:

THE AMERICAN PRINTING HOUSE FOR THE BLIND WANTS US TO TRY OUT A NEW TEST THEY HAVE DEVELOPED. THE PURPOSE OF THE TEST IS TO FIND OUT WHAT YOU KNOW ABOUT RAISED LINE DRAWINGS. MUCH OF THE TEST INVOLVES A SPECIAL KIND OF RAISED LINE DRAWING, CALLED A GRAPH. IN ALL, THERE ARE 64 MULTIPLE-CHOICE QUESTIONS FOR YOU TO ANSWER. YOU'LL ONLY DO PART OF THEM TODAY.

BEFORE YOU START THE TEST, LET'S GO OVER A FEW SAMPLE QUESTIONS. OPEN YOUR BOOKLET TO THE FIRST PAGE. AT THE TOP OF THE PAGE IS A QUESTION. READ THE QUESTION, EXAMINE THE RAISED DRAWING BELOW IT, AND CHOOSE YOUR ANSWER FROM THE FOUR POSSIBILITIES AT THE BOTTOM OF THE PAGE. THEN GO TO THE ANSWER SHEET, FIND THE RIGHT QUESTION NUMBER, AND CIRCLE YOUR ANSWER.

Point out to the student that the four answers at the bottom of the page are identical to those appearing on the answer sheet.

NOW GO TO THE NEXT PAGE AND ANSWER THAT QUESTION.

Point out to the student that there is only one question per page and that there are always four answers to choose from.

NOW TURN THE PAGE AND ANSWER THE LAST SAMPLE QUESTION.

Make sure that the student understands the test format and the proper usage of the answer sheets before proceeding to the test questions.

OK, YOU ARE READY TO START ANSWERING THE TEST QUESTIONS. CIRCLE AN ANSWER FOR EACH QUESTION. IF YOU ARE NOT SURE WHAT THE CORRECT ANSWER IS, TAKE A GUESS. DO YOU HAVE ANY QUESTIONS? NOW TURN THE PAGE AND BEGIN.

Note: This is not a timed test. However, the student should be encouraged not to spend an excessive amount of time on any particular question.

Monitor the student. Make sure that s/he is circling an answer for each question. Also make sure that the question number being marked on the answer sheet corresponds with the question number in the test booklet.

If the student wishes to change an answer, put an X through the first answer and circle the new answer.

ERIC

Before proceeding with the second test session, remind the student to mark an answer for each question. Once again, monitor the student's progress.

Do not tell the student that s/he will take the test again at the end of the semester. Doing so may bias the results of the second administration.

Return the completed answer sheets in the self-addressed, stamped envelope.

Second Administration

Record the student's name (or identifying code) and grade level at the top of the answer sheet. Also record your name and school.

Say to the student:

THIS IS THE TEST ON RAISED LINE DRAWINGS AND GRAPHS THAT YOU TOOK A FEW MONTHS AGO. I WOULD LIKE YOU TO TAKE IT ONE MORE TIME. ONCE AGAIN, THERE ARE 64 MULTIPLE-CHOICE QUESTIONS FOR YOU TO ANSWER. BEFORE YOU START THE TEST, LET'S GO OVER A FEW SAMPLE QUESTIONS. OPEN YOUR BOOKLET TO THE FIRST PAGE AND ANSWER THE QUESTION.

Have the student answer the three sample questions. Make sure s/he understands the test format and the proper usage of the answer sheets.

YOU ARE NOW READY TO START THE TEST. REMEMBER TO CIRCLE AN ANSWER FOR EACH QUESTION. IF YOU ARE NOT SURE WHAT THE CORRECT ANSWER IS, TAKE A GUESS. DO YOU HAVE ANY QUESTIONS? OK, BEGIN.

Monitor the student's progress.