THE EFFECT OF GRAPHIC FORMAT, AGE, AND GENDER ON THE INTERPRETATION OF QUANTITATIVE DATA

by

Helen Buchanan Miller

Dissertation submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

DOCTOR OF EDUCATION

in

Curriculum and Instruction

APPROVED:

John K. Burton, Chairman

J. Thomas Head

James W. Garrison

David M. Moore

Janet K. Sawyers

June, 1989

Blacksburg, Virginia

THE EFFECT OF GRAPHIC FORMAT, AGE, AND GENDER ON THE INTERPRETATION OF QUANTITATIVE DATA

by

Helen Buchanan Miller

Committee Chairman: John K. Burton
Curriculum and Instruction

(ABSTRACT)

The purpose of this study was to investigate the interpretation of numerical data when presented in four different graphic formats to different age groups and sexes. Fifth and sixth grade students (N=129) and eleventh and twelfth grade students (N=129) were assigned to four treatment groups. Each group viewed a different treatment slide with the same data displayed in one of four formats: table, line, line-table, or bar. After a narrative introduction, the students, while viewing the treatment graph, were asked to answer three types of questions: specific amount, static, and dynamic comparison. The students were then asked to continue viewing the graph for one full minute. After the minute elapsed, the projector was turned off and the students were asked to answer questions concerning the data presented on the graph.

A 4 (Graph Type) X 2 (Age) X 2 (Gender) multivariate analysis of variance (MANOVA) with repeated measures for the four types of questions was implemented to determine the relations among graph type, age, gender, and four types of questions. The independent variables were type of graph (between), age (between), gender (between), and type of question (within). The dependent variable was the interpretation of quantitative information as measured by the test questions.

The findings indicated that graphic format, age, and gender did affect the ability to interpret numerical data. The analysis demonstrated several statistically significant interaction effects: age and type of questions, graph and type of questions, and graph, age and type of questions. High-school students scored higher than elementary-school children on all four questions. Table graphs were effective for answering amount and static questions. As the questions became more complex, such as in a dynamic question, the table graph was one of the least effective means of graphic communication. For recall, the line-table format and line format were the most effective graphs. Age and gender differences emerged for particular graphs. Findings were discussed with regard to cognitive development implications.

DEDICATION

To my husband, , who without his love, support, and encouragement, this accomplishment would never have taken place.

To our children, , whose love, patience and enthusiasm encouraged me to fulfill this educational dream.

And, finally, to the memory of two educators, who by their example, inspired me to devote my life's work to education,

my mother,

and Steven's uncle, .

ACKNOWLEDGEMENTS

I wish to recognize and to thank the many individuals who provided the support to make this dissertation a reality.

To Dr. John Burton, my advisor, who constantly shared his time and expertise, and allowed to me to develop as a confident researcher and knowledgeable educator.

To the rest of my committee, Dr. Tom Head, Dr. Jim Garrison, Dr. Mike Moore, and Dr. Janet Sawyers who always took the time to answer my questions, to comment on my work, and to encourage my research.

To Dr. Tom Sherman and Dr. Lawrence Cross, who offered their valuable guidance and assistance.

To my colleagues in Educational Technologies, Dr. John Moore, , , , , , , Dr. Dave Taylor, and , who have given me their friendship, advice, encouragement, and assistance to make this year a truly rewarding, exciting, and fun year.

To my fellow graduate students, who have shared this entire experience and have been there with encouragement, understanding and friendship.

And finally, to my family, especially my sisters, , , and and my Aunt , who always knew I could do it.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The selection of the "right" graphic format to present quantitative data to various audiences continues to confront educators and instructional designers. Over sixty years ago, John Washburne (1927) investigated the effects of tabular, textual, and graphic arrangements on the recall of quantitative data. In his study, junior high school students were presented with one of 14 forms and were tested on their ability to recall specific amounts, as well as to make static and dynamic comparisons and rank orderings. Washburne, from this study, established some general rules for the appropriate use of various graphic, tabular, and textual forms. He stated that:

1. For static comparisons, use a bar graph.
2. For dynamic comparisons, use a line graph.
3. For specific amounts use a table.
4. Textual form is inappropriate for presenting more than two items of numerical data.

In 1989, Head and Moore used the Washburne study as a starting point for investigating the effect of graphic format on the interpretation of quantitative data. Their study developed some of Washburne's original textual information into a narrative, which was used as an oral introduction to the fictitious data presented. The data was fictitious to alleviate any effect of prior knowledge, and described the incomes of three European merchant groups during the middle ages. In their study with undergraduate college students, four graphic formats were compared: bar, line, table, and line-table. These four graphs were computer-generated slides, which enabled the researchers to present the information in a regulated format. That is, the graph designs were matched not only by quantitative data, but for color and shape. Their study was an improved methological revision of the Washburne study which tried to compare 14 different formats with few controls and limited use of statistical methodology. As in Washburne's study, three types of quantitative interpretation were tested, that of specific amounts, static and dynamic comparisons. They also investigated whether cognitive style (field dependence/field independence) correlated with the ability of students to interpret information in a specific chart. From their study, the following conclusions were presented.

1. For specific amounts and static comparisons, use a table graph.
2. For specific amounts and static comparisons, the line and bar graph did not differ.
3. For dynamic comparisons, use table or line-table graphs.

Their study did not produce an indication that there is a strong relationship between field dependent/independence and the students' scores on the different types of questions.

Almost as an afterthought, Head and Moore (1989) added five questions which requested the students to recall information from the particular graph (bar, line, table, and line-table) they had been viewing when interpreting the data. Interestingly, they found that the participants viewing the line, line-table, and bar graphs (in that order) obtained much higher scores than those viewing the table graph. This finding is one of the most interesting aspects of their study. Head and Moore suggested that a presenter must analyze the reason why a graph is being used in a presentation. For example, If the audience is to make judgements while viewing the graph, one type of graph should be used. But if the audience is to assimilate a general trend or focus of the data, and not exact quantitative values, then another graph is more appropriate. The study described here replicated the Head and Moore study, and expanded their research to include a more systematic investigation of these "imagery" effects as well as to extend the research to examine possible age and gender effects or interactions. In order to present a context for this work, it is necessary to examine the relevant literature from the areas of presentation graphics, information processing model, visual cognition, and cognitive development.

PRESENTATION GRAPHICS

The availability of computer-generated graphics has increased the possibility of easily designing and using professional looking graphics to present numerical information. Yet little reliable information exists, as to which of the various graphic formats are most effective, when used to communicate and instruct. Educators and researchers have suggested that the particular attributes of charts, graphs, and diagrams make it easier for people to understand and learn certain types of information. Winn (1987), for example, suggested that graphic formats are able to exploit spatial layout in a meaningful way. The efficient parallel processing of the graphic format, as compared to the processing needed for the verbal message, is one reason offered by Winn for the more effective communication of graphs. The characteristics of tabular charts, bar and line graphs are discussed in the following section.

Tabular charts or tables contain numerical information or data that is arranged in columns. They illustrate relationships among categories. For example, data obtained from social surveys could be listed in a table showing the questions and responses received from a questionnaire. Neither the persons responding nor the questions asked are a continuous variable, in the sense that time or temperature would be. Tables are compact means to present data, but are abstract in nature. As a result, Macdonald-Ross (1977) contended that people need time to calculate the relationship of data in a table. The bar and line graphs illustrate relationships among variables with at least one variable being continuous.

Bar charts may show more than one dependent variable and may be presented in a horizontal, vertical, or segmented fashion. The height of the bar is the measure of the quantity being represented. The bar graph shows variation in only one dimension, for example, the height of one plant over time or the heights of several students at any given time (Heinich, Molenda, & Russell, 1985). The use of the bar graph is recommended to compare or contrast specific amounts between one period and the next, and also to emphasize the amount of data in a series rather than emphasizing a trend (Griffen, 1988).

Line graphs are constructed on two scales at right angles. Each point has a value on the vertical scale (y-axis) and a value on the horizontal scale (x-axis). Lines are drawn to connect the points. This type of graph demonstrates variation on two dimensions (Heinich et al., 1985). For example, a line graph can show the relation between rainfall and month(s) of a year. Griffen (1988) suggested line graphs be used when data covers a long period of time and when the emphasis is on trends, estimates, or interpolations of the depicted data.

All three types of graphic presentations can display quantitative data. Their main objective is to allow the viewer to gain an understanding of, or the significance of, the data in some particular context (Macdonald-Ross, 1977). The graphic presentation gives the presenter the power to manipulate, evaluate, and organize quantitative data through the selection of different formats. Therefore, the question emerges that with such a variety of formats available, which graph should the instructor employ?

The first decision of the instructor is to determine the particular purpose of information to be displayed. Macdonald-Ross (1977) identified three questions that the communicator should ask in deciding how data is to be presented: 1) Which data to present? 2) Which format to choose? 3) How to execute that particular format? From the literature, the two last questions on the presentation of the data have been continually addressed (e.g., Cleveland & McGill, 1984; Eells, 1927; Macdonald-Ross, 1977; Washburne, 1927; Winn, 1987). Graph design for data analysis and presentation has largely relied on tradition, intuition, rule of thumb, and a kind of master-to-apprentice passing along of information (Cleveland & McGill, 1984). The ANSI manual on time-series charts (American National Standards Institute, 1979) admitted that the current usage of graphs was often established by general agreement, and not by scientific research. Can empirical research help the presenter decide the best method to present data? Macdonald-Ross (1977) and Cleveland and McGill (1984) proposed that the science of graph presentation should include both theory and experimentation to test it. Yet Macdonald-Ross suggested that one should not "...be so bigoted as to suppose that only formal laboratory experiments reported in the psychological journals can count as 'knowledge' " (p. 361). A place to begin is to review some of the landmark discussions and research on the usage of graphs.

Over two hundred years ago William Playfair published his work entitled The Commercial and Political Atlas (Schmid & Schmid, 1979). He created new and perceptive methods to analyze and portray quantitative data. To be fair, many basic concepts of graphs were utilized before Playfair's book was published, yet his book formulated and set the standards upon which modern graphic presentation are based. His contributions include the coordinate graph, circle graph, pie diagram, and the bar chart.

Brinton (1914) lauded the superiority of bar graphs over circle or pie graphs. He explained that the bar graphs allowed the eye to make comparisons of length which he judged to be easier than attempting to make comparisons of area and volume. In the late twenties several studies were conducted to refute this claim and to empirically evaluate and compare graphical methods (Croxton, 1927; Eells, 1926; Washburne, 1927). From these studies, a battle emerged over which graph was more effective: circle or bar. Macdonald-Ross (1977) insinuated that many of these earlier studies were marred by poor experimental techniques, including small numbers of subjects, inadequate stimulus materials, and inappropriate task criteria. In graph construction, Schmid and Schmid (1979) and Bertin (1973) have set the standards for clear presentation and interpretation of graphic form, while Tufte (1983) has pinpointed poor graphic displays and illusions.

Charts and graphs in the literature have often been viewed as a means to display data in attractive, succinct and readily understood format. The research focused on the advantages of graphs through visual chunking, mental imagery, and serial versus parallel processing. The question for an instructional designer should be what type of graph effectively and efficiently aids the learner in utilizing a strategy to solve a particular problem. In business, graphic display of quantitative data is heralded as the manager's salvation to quick and more efficient decision making. Takeuchi and Schmidt (1980) suggested that a visual format is more easily understood, enabling trends and deviations to be evaluated without reading through a large amount of data printouts. Managers using graphs can evaluate and decide issues within a relatively short amount of time. In this approach the focus is on development of strategies for graphic presentations.

Winn (1987) proposed that graph designers believe that the particular attributes of charts, graphs, and diagrams do aid people in gaining information and making inferences from graphic forms. Waller (1981) used the term "visual argument" to suggest that instruction is often more effective if explained pictorially instead of verbally. Macdonald-Ross (1977a) and Reed (1985) proposed that visual representations require students to use an entirely different type of logic based on the meaningful use of space and the position of elements in a graphic. It is suggested that these visuals offer more information than is available through words alone. For example, Novak (1979) explained that "concept maps" which represent concepts spatially in networks or in charts, show how these concepts are related to one another, while a listing of these same concepts would not accomplish this. Winn (1987) described schooling as biased toward verbal forms of representation. As a result, Winn suggested that students are not able to learn to solve problems that may be solved more productively in a visual presentation. For example, in a study by Winn (1987), a computer screen, displaying letter patterns, was divided into quadrants, modeling a "chunking" strategy. This technique helped students learn the patterns more successfully than students for whom the strategy had not been modeled. Winn concluded from this research, and studies done by Salomon (1974) and Bovy (1983), that graphic displays can encourage the use of cognitive processes which involve the operations of visual chunking, mental imagery, and parallel processing.

In the cognitive model, the visual memory system has been shown to be effective in pattern recognition. Sless (1981) suggested that while the visual system can recognize certain forms with ease, the system finds it very difficult to assimilate quantitative data. Cleveland and McGill (1984) proposed that the visual system is very good at recognizing geometric shapes and presented a perceptual building block of several elementary perceptual tasks that people use to extract quantitative information from graphs. These perceptual tasks are:

1. position along a common scale
2. position along nonaligned scales
3. length, direction, angle
4. area, volume, curvature
5. shading, color saturation

They suggested that the viewer performed one or more of these mental-visual tasks to interpret the values of real variables represented on most graphs. The power of a graph, according to these researchers, is its ability to enable the viewer to see the patterns and structure not readily revealed by other means of presenting the data.

The literature in the area of presentation graphics suggests two questions which are at least two centuries old:

> Which graphic format among table, line, bar, and line-table generally enables the learner to more accurately interpret quantitative data?
>
> Which specific graphic format among table, line, bar, and line-table enables the learner to more accurately answer amount, static and dynamic questions?

INFORMATION PROCESSING MODEL

Cognitive psychologists are interested in explaining how knowledge is processed by human beings. In his 1967 book, Cognitive Psychology, Neisser presented his information-processing model of the internal activities that intervene between stimuli and responses in human memory. The model was a synthesis of earlier attempts to apply information theory and computer analogies to learning (Bartlett, 1958; Broadbent, 1958; Miller, 1953; Posner, 1964a).

The information-processing approach focuses on how the human memory system acquires, transforms, compacts, elaborates, encodes, retrieves, and uses information. The memory system can be divided into three main storage structures: Sensory Registers, Short-term Memory (STM), and Long-term Memory (LTM). Each structure is synonymous with a type of processing. The first stage of processing is registering the stimulus presented to the system. The sensory registers briefly hold the information introduced by one of the five senses until the stimulus is recognized or lost. Pattern recognition is the matching of stimulus information with previously acquired knowledge. Klatzky (1980) referred to this complex process as assigning meaning to a stimulus. Once the stimulus is recognized it passes to the next storage structure, short-term memory. Unlike the sensory registers, STM does not hold information in its raw sensory form (e.g., visual - "icon," auditory - "echo") but in its recognized form. For example, the letter "A" being recognized as a letter and not just a group of lines. STM can maintain the information longer than the sensory registers, by a holding process known as maintenance rehearsal, which recycles material over and over again as the system works on it. Without the rehearsal the information would decay and be lost from STM. Another characteristic of STM is its limited capacity for information. Miller (1956) determined that STM has room for only about seven items or chunks of information. Klatzky (1980) defined STM a "work space" in which information may be rehearsed, elaborated, used for decision making, lost, or stored in the third memory structure, long-term memory. LTM is essentially a complex and permanent storehouse for an individual's knowledge about the world and his/her experiences in it. LTM processes information to the two other memory structures and in turn receives information from the sensory registers and STM. First, the stimulus is recognized in the sensory registers by a comparison of information in LTM. Second, information manipulated in STM can be retained in more permanent storage in LTM.

According to Cleveland and McGill (1984), researchers should search for a model, based on a scientific foundation, for graphic presentations. The information-processing model provides a process by which graphic representations are decoded and encoded. Cochran, Younghouse, Sorflaten and Molek (1980), stated that researchers using cognitive models must demonstrate the appropriateness of their models in two ways: 1) It must be shown that the models are appropriately descriptive of the phenomena and; 2) It must be shown that the models of mental processes are adequate to account for, or are able to explain how, the organization and coordination of mental operations can specify the cognitive processes that perform the experimental tasks. Graphic interpretation, therefore, should be analyzed by how the user decodes and encodes visual information. In understanding how the individual interprets visual stimulus, one begins to grasp the variety of operations and transformations of mental representations that enable the person to solve a problem. The strategies used by the individual are based on his own personal information-processing system and experience.

Anderson (1985) suggested that all cognitive activities are fundamentally problem-solving ones. He contended that human cognition is always intentional in the sense that it is organized toward achieving a goal and removing obstacles to those goals. Problem solving, as depicted in the information-processing model, is a complex mental activity that includes the interaction between the task environment and the individual problem solver (Newell & Simon, 1972). The task environment is the description of the problem and how it is represented to the individual. This description contains the information, assumptions, restrictions, and context in which the problem was presented (Magliaro, 1988). The essential feature of solving the problem is the ability of the individual to break down the original goal into subgoals that can be achieved by direct action. It is reasonable to assume that individuals will differ in their approaches, time involved, and success in problem solving. The difference is often equated to the difference between an experienced problem solver and a novice (Magliaro, 1988).

To understand how an individual is able to solve a problem, the researcher must first focus on the decisions made at each level that lead to the final goal attainment. Within the information-processing model, attention and pattern recognition determine the environmental factors needed to solve problems. A large amount of information impinges on the sensory registers, but is quickly lost if not attended to. Attention, therefore plays an important role in selecting sensory information for problem solving. Attention is conceived of as being a very limited mental resource (Anderson, 1985). It is difficult to perform two demanding tasks at once, such as talking and writing at the same time. Whereas all information is registered by the sensory registers, only information attended to and processed to more permanent form is retained. Bruner, Goodnow, and Auston (1967) stated that a person will tend to focus attention on cues that in the past have seemed useful. Pattern recognition enables the individual to organize perceptual features (cues) so that relevant knowledge from LTM is activated. Pattern recognition integrates information from a complex interaction which utilizes both bottom-up and top-down processing (Anderson, 1985). Bottom-up is the use of sensory information in pattern recognition. Top-down is the use of pattern context and general knowledge. Once relevant information is activated from LTM, the individual focuses attention on the relevant stimuli and brings it into the working memory, STM.

Long-term memory contains large quantities of information that have to be efficiently organized so that it can be effectively encoded, stored, and retrieved. All three processes are interdependent. For example, the method of presentation determines how information is stored and retrieved (Klatzky, 1980). Encoding is related to the amount of elaboration and rehearsal conducted in STM. This elaboration uses the information received from LTM after the stimulus is recognized. As the new information is compared to the old and manipulated it is either added or subsumed into the existing schema and then encoded in LTM (Anderson, Greeno, Kline & Neves, 1981). As information is restructured, new structures are formed which result in new conceptualizations (Magliaro, 1988). These knowledge structures combine information in a very organized manner. Evidence for memory storage indicates that representations can be both meaning-based and perception-based. Retrieval of information is an active process as is encoding. Information is accessed by a search of the memory structures. The speed and accuracy of retrieval is directly dependent upon how the information was encoded and the attention being given to the stimulus. To be recalled from LTM, information must be activated. The level of activation seems to depend on the associative strength of the path. The strength of the activation increases with practice and with the associative properties (Anderson, 1985).

Using various graphic formats in an experimental task where people are asked to perform mental operations may provide evidence about the way that cognitive processes operate to solve a specific problem. Larkin and Simon (1987) proposed that a graphic representation may be more effective than a sentential (text) one due to the reduction in search and computation of elements in the problem. Their premise was that if two representations are informationally equivalent, their computational efficiency would depend on the information-processing operators that are in operation. While a diagram and text may hold the same information, the individual may recognize features readily and efficiently in a diagram due to the information being organized by location and, therefore, reduce the search and computation time to solve the problem. Larkin and Simon proposed that the cost of computation must be included in any judgement of the relative efficiency of two representations. To empirically test their views, the researchers used two representations of a problem in physics which contained identical information with one in diagrammatic representation and the other in sentential format. The data structure for the diagram was indexed by location in a plane where many elements shared the same location and each element would be adjacent to any number of other elements. The data structure for the sentential representation was indexed by a position in a list, with each element "adjacent" only to the next element in the list. Their conclusions specified that the diagram was more efficient for making inferences. Yet, the point was made that some problem solvers are not able to effectively use the diagrams. They concluded that a diagram, to be useful, must be constructed correctly to take advantage of certain features and, secondly, that the failure to use the pertinent features of diagrams seems to be a reason why certain people are not good problem solvers. They may have to be trained in order to use the diagram to solve the problem.

To understand how a learner would interpret a graph, the information-processing approach would focus on the ability of the learner to process visual stimuli. That is, how the human brain recognizes, categorizes, and interprets visual information. It seems necessary to clarify the processing and storage of visual input in order to draw conclusions on the effectiveness of graphic presentations.

VISUAL COGNITION

Psychologists and educators are interested in understanding how individuals are able to process information and then how they utilize that information to solve a problem. The use of visual materials by educators to enhance the learning process is an accepted instructional technique. Dale's Cone of Experience theory (1946) supported the use of visual aids. Dale described an instructional continuum with concrete experience on one end and written and spoken language at the other end. Within this framework, visual material becomes a necessary component for helping the inexperienced learner to bridge the gap between concrete experiences and symbolic representations of real-world phenomena. Dwyer (1978), one of the most prolific researchers on the use of visuals in learning, stated that visuals (television, pictures, slide presentations, diagrams, graphs) are effective in teaching facts, concepts, and procedures. Levie (1987) suggested that visuals can be useful in analogical reasoning by making abstract information more concrete and imaginable. For example, the use of diagrams in mathematical word problems.

Perceptual research focuses on the question of how mental representations are recognized, manipulated, encoded, and retrieved. Does visual information function differently in processing than verbal information? The representation of visual images is both perception-based and meaning-based knowledge (Anderson, 1985). Spatial images retain information about the positions of objects in space. The memory of the visual image can also be a meaningful representation. For example, the memory of a chess board would generate not only the positioning of the pieces but also be remembered by their meaning to a chess game.

Posner's (1969) research with letter matching experiments supported two ideas: 1) visual information can persist in short-term memory (STM) after the stimulus is no longer available and; 2) visual information can be retrieved from long-term memory (LTM). Kosslyn, Ball and Reisner (1978) suggested that people are able to scan over mental images of a map and make judgments similar to what would be expected if they were looking at an external map. The visual image seems to represent the stimulus item. Kosslyn (1975) and Baddeley, Grant, Wight, and Thomson (1975) interpreted visual images as having limited capacity in STM. This processing limitation was reflected by similar limitation of acoustic codes.

How are mental representations encoded in long-term memory? Cognitive psychologists debate two basic positions; imagery and propositions. Imagery depicts mental images as internally coded in a spatial structure of items. Propositions suggest that mental images are encoded in terms of linear orderings that sequence the items. Both positions support a hierarchical organization in which subimages or sublists can occur as elements in larger images or lists (Anderson, 1985). The pro-image group (e.g., Kosslyn & Pomerantz, 1977; Paivio, 1971, 1986; Shepard, 1967) argues that visual imagery is encoded by properties that are spatial and modality specific. Paivio (1971, 1986) explicitly promoted a dual-coding system. The anti-image group (e.g., Anderson & Bower, 1973; Pylyshyn, 1981) argue that imagery is encoded in an abstract propositional format which would serve as a neutral format for both pictorial and verbal information. The imagery arguments give strength to the position that charts, graphs, and diagrams are useful in communication and instruction.

The basic assumptions of the pro-image group as interpreted by Kosslyn and Pomerantz (1977) are:

1. An image is a spatial representation like that underlying the experience of seeing an object during visual perception.
2. Only a finite processing capacity is available for constructing and representing images. This will tend to limit the amount of detail that may be activated at any one time.
3. Images, once formed, are wholes that may be compared to percepts in a template-like manner.
4. The same structures that represent spatial information extracted during vision also support images.
5. Many of the same operators (excluding peripheral functions) that are used in analyzing percepts are also applied to images.

The imagery theorists make a distinction between codes used for visual and verbal information. Paivio (1971, 1986) developed the dual-code model which stated that the two types of information (verbal and visual) are encoded by separate subsystems, one specialized for visual images and the other specialized for verbal language. The two systems are assumed to be structurally and functionally distinct. Paivio (1986) defined structure as the difference in the nature of representational units and the way in which these units are organized into higher order systems. Structure, therefore, refers to LTM operations which correlate to perceptually identifiable objects and activities either verbal or visual (Paivio). Functionally, the two subsystems are independent, meaning that either can operate without the other or both can work parallel to each other. Even though independent of one another these two subsystems are interconnected so that a concept represented as an image in the visual system can also be converted to a verbal label in the other system, or vice versa (Klatzky, 1980). For example, a stimulus picture is presented along with its name, it therefore would be encoded in both the visual and verbal subsystems. Thus, a stimulus would be dual-coded, which Paivio suggested could explain why visual pictures are often remembered better than verbal information (Pressley & Miller, 1987). Such a conclusion would offer support to using graphs, charts, and diagrams as visual aids to learning, as they can display certain quantitative data in both visual and verbal aspects.

Dual-code theorists advocate that mental images are not exact copies of pictures, but instead contain information that was encoded from a visual after perceptual analysis and pattern recognition (Klatzky, 1980). It is thought that the images are organized into subpictures at the time of perception (Anderson, 1978). Paivio (1986) further explained that mental representations have their developmental beginning in perceptual, motor, and affective experience and are able to retain these characteristics when being encoded so that the structures and the processes are modality specific rather than amodal. For example, a concrete object such as the ocean would be recognized by more than one modality--by its appearance, sound, smell, and taste. Therefore, a continuity between perception and memory as well as behavioral skills and cognitive skills is implied (Paivio). This theory also states that the visual system is simultaneously or synchronously organized. For example, on a perceptual level a face is seen as the sum of all its parts. And on a cognitive level, mental images can be processed simultaneously so that one can see and possibly scan an entire complex scene, such as a graph.

The concept of limited space was demonstrated by Kosslyn (1975) who asked students to visualize two named objects and then to answer questions about one of the objects. Students were slower to find parts that were next to an elephant than to find those next to a fly. Short term memory (STM) for visuals appeared to have a processing limitation. Retrieval of visually coded material also differs from other forms of internal representation. As previously stated, information is available simultaneously rather than by a sequential search and can be located by template or by an unlimited-capacity parallel search (Anderson, 1978).

Dual-coding theory can account for our personal impression of having images. The theory is often supported by research studies that conclude that individuals have a continuous and analogue ability to judge space from images, (Kosslyn, 1985) and finally for studies which indicate strong visual memory abilities. Paivio's theory is also able to effectively support the recurrent finding that memory for pictures is better than memory for words (Shepard, 1967), otherwise known as the "pictorial superiority effect" (Levie, 1987). The pro-image approach is able to support the individual's ability to respond adequately to cognitive tasks which require the learner to evaluate and manipulate mental images to solve problems. Imagery theory has been used by researchers to construct and test hypotheses on learning from graphics (Winn, 1987).

A review of the literature in the area of visual cognition suggests an additional question:

> What graphic format (table, line, line-table, bar) is the most effective when the learner is attempting to recall (imagery) numerical data?

COGNITIVE DEVELOPMENT

The study of cognitive development examines the processes and products of the developing human mind. Its study is motivated by both scientific curiosity and a desire for practical applications. The traditional view of cognition recognizes such "intellectual" entities as knowledge, consciousness, intelligence, thinking, creating, strategies, imagining, reasoning, inferring, problem solving, conceptualizing, classifying, symbolizing and dreaming. A contemporary view of cognition would also include the following processes as an integral part of cognition: social cognition (human versus non-human objects), organized motor movements, perception, imagery, memory, attention, and learning (Flavell, 1985). Cognition, so defined, includes all human psychological processes and activities. Given such an inclusive definition, Flavell explained the complexity of cognition by stating that ..."the psychological events and processes that go into making up what we call 'thinking,' 'perceiving,' 'remembering,' and the rest are in fact complexly interwoven with one another in the tapestry of actual, real-time cognitive functioning." (1985, p. 3) Each process is involved in the development and operation of the other processes, affecting them and being affected by them. For example, problem solving involves the integration of several cognitive processes, such as, attention, memory, organization, classifying, and inference. Human cognition is a complex, organized system of interacting components. In discussing its development these interactions are continually addressed. Two models associated with cognitive development are the Piagetian model and the information-processing model. In analyzing these theories one must compare the ability of each to predict behavior while being consistent with past observations.

Jean Piaget is the best known researcher in the area of cognitive development. Many of his observations made over thirty years ago have been largely confirmed in controlled experimental studies. In his research, Piaget used a clinical approach to studying the growth of knowledge in children by recording and interpreting the development of his own three children. These detailed studies of the early life of his children became the basis of three of his books, The Origins of Intelligence in Children (1952), Play, Dreams, and Imitation in Childhood (1951), and The Construction of Reality in the Child (1954). Piaget's theory of cognitive development incorporates the role of both maturation and learning.

Piaget, trained as a zoologist, maintained that humans are alive, striving to survive and, therefore, function by taking in information, relating it to their existing knowledge base, and then reformulating it. A person is viewed as continually assimilating new information and making changes in his mental organization to accommodate the new knowledge. The progressive changes in cognitive structure may vary from person to person, but they follow a prescribed genetic sequence. Each stage is cumulative with knowledge and skills gained in one carried over into the next stage. Therefore, Piaget rejected the idea that one stage could be circumvented in moving to a later stage.

Piaget's four main stages of development with approximate ages are: sensorimotor (0-2 years), preoperational (2-7 years), concrete operation (7-11 years), and formal operations (11-adult). He based his stages on two premises, that of structure and operations. The structure is how a person represents her world and the operation is how the person acts upon this representation. The stages represent progressively more developed cognitive structures and hence are accompanied by improved and more powerful cognitive operations.

The sensorimotor stage views the child in terms of his actions. Infants learn to coordinate their senses with motor activity, by actions such as sucking, reaching, looking, dropping, etc. In this stage the newborn moves from a reflexive individual to one who attempts to control and investigate his environment. The preoperational stage views the child as engaging in internal thought about his world. The child deals with concrete images which are limited by six problems suggested by Phillips (1969).

1. concreteness--deal with only concrete objects that are physically present.
2. irreversibility--child is unable to rearrange objects mentally or to conceptualize them in another grouping.
3. egocentrism--child believes everyone sees the world from the same perspective as she does, thus experiencing what she is experiencing.
4. centering--child can only attend to one dimension of a problem.
5. states versus transformation--child focuses on how things look (states) rather than on the operations that produced them.
6. transductive reasoning--child reasons that if A caused B then B must have caused A.

The concrete stage begins as a child is able to represent the world not as static perceptual images but rather as concrete objects that can be manipulated mentally and logically. At this point, the child can use the operations of reversibility and decentralization. For example, a child in this stage would recognize five pennies as the same amount no matter if they are spread out or bunched together. The child can also judge how others would view a situation, everything is not seen just from their own perspective.

In the area of children's perceptions of gender roles and how this awareness influences children's self-perceptions, preferences, and behaviors, differences begin to emerge as the children enter the Piaget's concrete stage of development. Huston (1983) stated that after about age 7, children's awareness of societal stereotypes tends to increase monotonically with age up to adolescence. Acceptance of stereotypes as inflexible tends to decline during the elementary and adolescent years. Children do demonstrate flexibility in later childhood, yet boys' and girls' preferences follow different developmental paths. Boys continue to show a preference for masculine activities, while girls' preference for feminine activities increases until five, but after that age it tends to decline and interest increases in masculine activities (Hartup & Zook, 1960).

Studies of children from 2nd to 12th grade have shown that athletic, spatial, and mechanical skills are viewed as masculine while verbal, artistic, and social skills are considered feminine. Elementary children do not tend to consistently stereotype math and science. But, by high school age, students tend to think of these subjects as strictly masculine (Boswell, 1979; Stein, 1971). These differences have been well documented. Girls perceive math as more difficult than boys, and have a lower expectancy of success than do boys, even if actual performance is the same (Brush, 1979). This phenomena helps explain the tendency for boys to pick advanced math courses more often than girls (Steel & Wise, 1979).

Maccoby and Jacklin (1974) suggested that girls were superior in verbal skills, while boys were superior in spatial and mathematical skills. These differences in math did not appear until high-school level. Gender differences in visual-spatial tasks were also demonstrated beginning in middle childhood with the boys doing better than the girls (Thomas & Jamison, 1975). Due to males' preference for math and science, they tend to receive more training in visual-spatial activities than females.

Piaget's final stage of development, formal operations, begins when the individual is able to think in abstract terms. The individual is now able to consider hypothetical situations and discuss probabilities. After emerging from this stage, the individual, according to Piaget, has become an adult conceptually and is capable of scientific reasoning (Anderson, 1985).

As stated, earlier research has largely confirmed many of Piaget's observations, although sections of his developmental account have warranted revision and reinterpretation (Anderson, 1985; Flavell, 1985). One model that has redefined and clarified Piagetian theory is that of information-processing. This model reiterates the Piagetian concept that the human system is constantly reorganizing by assimilating and accommodating information. Its primary objective theoretically, as Flavell states, is to provide an accurate, detailed understanding of what the human cognitive system actually does when attempting to solve a particular problem.

In the information-processing model the structure of the system is complete by about age 4 years and remains invariant over a person's life span (Kail, 1979; Klahr, 1980). The further development of the child's cognition is explained by the child's increasing familiarity of cognitive structures and the ability to use processes more efficiently (Gross, 1985). Children are viewed as able to transform rules and acquire strategies that allow them to assimilate knowledge and propel themselves into a higher stage of development.

Piagetian and information-processing models offer explanations of how the human cognitive system develops. Piaget emphasized the progressive development of both the structure and processing elements of an individual's cognitive system, but focused primarily on the structure. Information-processing focuses on the progressive development of the processing ability of the individual, theorizing that the structure remains stable after the stage of infancy. Due to their differing emphasis, the theories are more often viewed as complimentary rather than adversarial.

Both the information-processing approach and the Piagetian approach agree that the ability to use memory efficiently increases with age. Information-processing model proposes that the improvement of memory reflects the child's ability to use effective operative processes within the structure of the cognitive system.

Sensory registers are the points that information is received from the external world. Stimuli are received through the senses with information entering mainly from visual and auditory senses. Studies examining iconic (visual) and echoic (auditory) memory have generally found that the speed at which a stimulus is processed increases as the child grows older (Cowan, Suomi, & Morse, 1982; Lasky & Spiro, 1980; Welsandt & Meyer, 1974). Young children have difficulty in processing information quickly. Sheingold (1973) concluded that decay of information is prevalent in young children due to their inability to process information quickly. Observations of adults interacting with children reflect the intuitiveness of this concept, for adults tend to use a slow deliberate rate of presentation of both speech and visual stimuli when interacting with children (Gross, 1985). For example, adults tend to slowly turn the pages of a picture book when they read the book to a small child.

Why children do not process as quickly as adults is not entirely clear. Gross (1985) suggested that the problem may be with stimulus and task familiarity and not with the structure of the sensory registers. In processing sensory information, people need to attend to a number of dimensions. Young children may have difficulty concentrating on more than one dimension. Visually, one may have to attend to identification and spatial positioning. Finkle (1973) presented dot patterns to kindergarten, third graders and sixth graders, and college students. Following tachistoscopic presentation of the dots, the students had to reconstruct the patterns. Although older students did better than the younger ones, across age levels the number of positions recalled correctly continued to increase as more dots were added to the pattern. In a second experiment by Finkle, the introduction of one bit of identity information into an array (a substitution of a dot by another geometric form) produced a decline in the younger children's recall of position information. It seems likely that young children have difficulty in simultaneously processing identity and position. Yet Eimas and Miller (1980) suggested that at least with acoustical information (place of articulation, stress, intonation, and pitch) that even young infants are capable of simultaneously processing more than one acoustical feature.

A review of the development of selective auditory attention reveals a progressive improvement in children's ability to listen selectively (Geffen & Sexton, 1978; Hiscock & Kinsbourne, 1980). Broadbent (1958) proposed that selective attention occurs through the selective filtering of information. Lane and Presson (1982) indicated that with age, one becomes more adept at focusing on the central task itself. Doyle (1973) concluded that young children are distracted by competing auditory messages. Children were asked to listen to lists of simultaneously presented word pairs, repeating the words on one list while ignoring the other list of words. Older children recognized more words. Gross (1985) suggested that the problem is one of faulty methodology. Listening to words presented to both ears is not a natural task for children, while watching TV probably is. For example, young children demonstrated the ability to shift their attention appropriately between sources of information while viewing a television show.

Generally the literature suggests that young children tend to possess less skill, than older students, in their ability to process information stored in the sensory registers. Several possible reasons are suggested for this inadequacy. It may be related to developmental changes, or lack of facilitating strategies, or it could be the type of unrealistic task in the experimental design that was attempted.

Short-term memory (STM) receives information that has been recognized in the sensory registers and retained long enough to send it to this storage system. It is estimated that duration of information for both children and adults in STM is very short (approximately 20 to 30 seconds) without some type of active attempt to retain it. Researchers (Peterson & Peterson, 1959; Rosner & Lindsay, 1975) concluded that children have greater difficulty retaining information in STM than adults.

The amount of information that can be retained in STM is considered its capacity. Adults again are estimated to have a greater capacity for information than young children (Mandler, 1967; Miller, 1956; Liben, 1979). As children approach the upper elementary grades there is little difference between them and adults in their capacity to hold information (Belmont, 1972; Farnham-Diggory, 1972; Liben, 1979). Case (1978) reasoned that children's apparent growth of capacity of STM is the result of simple strategies becoming more automatic through use, and then being modified into more powerful strategies that allow for chunking of information held in STM.

Another study that supports the concept of improved capacity is Chi's (1976) chess problem. A typical test of capacity for working memory is the digit span test. In general, digit span ability (string of digits recalled) increases with age. Piaget proposed that adults have structurally larger working memories than children. Case concluded that adults have developed better strategies. To answer this question, Chi (1978) gave tests of digit recall and tests of recall of chess pieces to a group of children and adults. As expected, the adults were able to recall more digits, but the children were able to recall more chess pieces. The children, whose average age was 10.5, were knowledgeable about chess while the adults were not chess players. The results disproved the concept that the structure of working memory increases with age. Chi suggested that the participants' experience with techniques for grouping items would explain the results. To an adult, a set of two or three numbers may be held as a single unit, while a chess player may group several chess configurations as a single unit.

Information is represented in STM in a variety of modalities, such as auditory-verbally, visually, and semantically. Studies with adults reveal the tendency for adults to talk to themselves as they do mental work, indicating encoding in an auditory-verbal mode (Atkinson & Shiffrin, 1968). Studies with pre-schoolers indicated that they tend to think with pictorial representations (Cramer, 1976; Hayes & Rosner, 1975). For example, Brown (1977) found that kindergartners made more errors in recalling visually similar letters sets in comparison to auditorally similar ones. Research completed with real world phenomena (TV watching) indicated that while visual information may be the preferred mode of encoding, children do not have difficulty encoding auditorally. Several researchers have suggested that perhaps the auditory messages may serve as attentional devices, directing children's attention to important aspects of a program (Calvert, Huston, Watkins, & Wright, 1982).

If the structure of STM is developmentally the same for adults and children as the information-processing model suggests, then why are there differences in memory ability between children and adults and differences in middle childhood and adolescence? One aspect that has already been discussed was the attention capacity of the different age levels. Another area for discussion is the use of cognitive processes such as rehearsal, chunking, imagery, organization, and elaboration, collectively known as cognitive strategies.

Maintenance rehearsal is the repeating of information over and over in order to maintain it in STM. Flavell, Beach, and Chinsky (1966) demonstrated an increase with age in the spontaneous use of verbal rehearsal. In their study using children of ages 5, 7, and 10, seven pictures of common objects were displayed. The children understood that their task was to recall three of the pictures in a certain order. In observing the twenty children in each age group, verbal rehearsal of the names of the pictures was evident for two 5 year olds, twelve 7 year olds, and seventeen 10 year olds. In an extension of this study Kenney, Cannizzo, and Flavell (1967) used the same procedure with a group of first graders, considered a transitional stage, at which some would be expected to rehearse and others would not. There were four major findings. First, children who spontaneously rehearsed remembered more pictures. Second, nonrehearsers could learn to rehearse with minimal instruction, and third, when they did, they obtained scores that matched those who spontaneously rehearsed. Fourth, when given the option on later trials of rehearsing or not rehearsing, more than half of the new recruits to rehearsal abandoned the strategy. In view of these findings, Flavell (1970b) defined a production deficiency and a mediational deficiency. Production deficiency for a specific strategy means that the child does not produce or reproduce the strategy, even though they have the ability and the skill to enact it. Mediational deficiency is the inability of the children to aid recall even if they try to use a specific strategy. Overall rehearsal is responsible for extending the amount of time that information can be maintained in STM.

The next strategy discussed is thought to increase the capacity of STM. Chunking involves grouping information together to form larger units. In a study involving first, fifth, and ninth graders, Rosner (1971) instructed children to learn a series of pictures by either rehearsing the items or by chunking the pictures together. The first graders failed to make use of either strategy while the older students were able to use both strategies effectively.

Several studies have demonstrated that words which illicit high imagery are easier to remember than low imagery. For example, the words ice cream illicit high imagery while the word noble does not. When older children and adults are instructed to use visual images, memory for these items is enhanced (Kosslyn & Pomerantz, 1977). Young children who appear to have better factual knowledge of information when it is presented visually, do not profit from imagery instructions as much as older children and adults (Reese, 1970; Rohwer, 1970).

Organizational techniques also seem to demonstrate developmental trends. Older children use categorical properties of word lists to help recall (Lange, 1973) and they are able to cluster to a greater degree than younger children (Vaughan, 1968).

The previous section has shown that younger children do not use a number of strategies that would enable them to use STM more efficiently. Training can help children gain in their ability to better use STM, but many times children, if not developmentally receptive, will not transfer this training to another situation.

Long-term Memory (LTM) is highly organized storehouse of all of a person's knowledge. It enables a person to recall events, solve problems, recognize patterns; essentially it is our ability to think. As previously stated there are several hypotheses on how information is encoded and retrieved in LTM. The discussion in this section focuses more on developmental issues rather than on mechanical aspects of LTM.

Information-processing model adheres to the concept that the organizational structure of LTM is basically stable after the period of infancy.

The main thrust of the theory, therefore, is the actual processing of information. Researchers in several studies (Anderson & Bower, 1973; Collins & Quillian, 1969; Kellas, McCauley, & Farland, 1975; and Nelson & Kosslyn, 1975) aimed primarily at demonstrating the nature of LTM organization, concluded that across age levels the contents of LTM are highly organized along associative dimensions. The difference found was that the types of associations made by children were more varied and idiosyncratic than adults. For example, young children may categorize cats, dogs, and furry slippers as animals, but not view snakes and frogs as part of this category. Two developmental processes that demonstrate how children begin to organize more effectively are integration and differentiation. Gross (1985) proposed that both processes are likely working together rather than an either/or explanation. Through integration children move from fragmented and incomplete concepts to more sophisticated groupings. For example, the ability to now include snakes and frogs in the animal category. By differentiation, children would delete irrelevant items from groupings; furry slippers would be dropped, for example.

Piagetian theorists would explain the expansion and revision of knowledge in LTM as a combination of structural maturation and revision of existing schemata. For example, the structural concept of decentralization would emphasize a child's ability to move from viewing the world from a "me" position to accepting others perspectives. Information-processing theorists have modified and clarified this Piagetian position by focusing on the child's ability to use hypothesis testing, rule knowledge, and the use of strategies.

Problem-solving research reflects the information-processing model of cognitive development. An integrated approach, that is how the sensory registers, short-term memory and long term-memory structures function together, is necessary in analyzing cognitive developments. For instance, children's ability to utilize a learned strategy located in long-term memory depends on the child's ability to initially attend to relevant stimuli (sensory registers), and then to work with this information and organize it (STM), and finally to reach the goal of solving the problem.

Gholson, Levine, and Phillips (1972) identified three strategies that utilize the entire cognitive process, that of focusing, hypothesis checking and scanning, and finally that of dimension checking or analyzing appropriate strategies. Researchers have made several conclusions that reflect age-related changes in children's use of hypotheses, rules, and strategies. The next section specifies several of these observations.

Gholson et al. (1972) demonstrated that children do not spontaneously use hypotheses above chance levels until approximately second grade. This corresponds to the onset of Piaget's concrete stage of development. For example, a younger child may not abandon a hypothesis even when it proves to be wrong, such as a continual search in the same place for a toy when the child has previous checked.

Several studies attempted to train children to use developmentally more advanced problem-solving rules and strategies (Anderson, 1968; Cantor & Spiker, 1978). Improvements in performances were gained, but children tended not to continue to use or spontaneously use the instructed strategies on their own. Gross (1985) suggested that several complex factors influence problem solving such as knowledge base, ability to generalize information and the motivation of the child.

In a synthetic approach, Siegler (1981) proposed a four-rule system that depicted changes in children's approach to problems requiring a knowledge of equilibrium. The problem was to determine whether or not a two-armed scales would balance or tilt to one side. His four-rule classification demonstrated a reliable age sequencing. By age 4, half of the children used Rule 1, with nearly all 5 years olds using it. Older children (8 and 12 year olds) generally used 2 and 3. While most college students used rule 3 with less than a third using the most advanced rule 4. As the rules became more complex the individual had to focus on more than one dimension, sequencing expectancies with actual outcomes and revising one's criteria for expecting certain consequences. Siegler argued that much of cognitive development consists of acquiring more powerful rules. Older children it seems have accumulated more knowledge, and an ability to process information because they have practiced operations more and therefore develop more effective strategies.

From the review of the literature in the area of cognitive development several final questions emerge:

> Are there gender differences in the ability to utilize graphic formats to interpret numerical data?
>
> Are there age differences in the ability to utilize graphic formats to interpret numerical data?
>
> Are there any interactions among or between the variables of age, gender, graph formats, and types of questions?

RESEARCH QUESTIONS AND METHODOLOGY

1. Which graphic format among table, line, bar, and line-table generally enables the learner to more accurately interpret quantitative data?
2. Which specific graphic format among table, line, bar, and line-table enables the learner to more accurately answer amount, static and dynamic questions?
3. Are there gender differences in the ability to utilize graphic formats to interpret numerical data?
4. What graphic format (table, line, line-table, bar) is the most effective when the learner is attempting to recall (imagery) numerical data?
5. Are there age differences in the ability to utilize graphic formats to interpret numerical data?
6. Are there any interactions among or between the variables of age, gender, graph formats, and types of questions?

METHOD

Participants

The participants for this study were 305 students enrolled in two different elementary schools and two different high schools from one rural public school system in southwestern Virginia. A total of 47 students were dropped from the study. One high school student was eliminated, as she was an exchange student and expressed concern in understanding the oral questions. Three elementary students were eliminated due to incomplete answer sheets. All the children from the fourth grade class (43) were eliminated from the study due to interruption of the testing period by a fire drill and the inability of half the students to complete the task. In the final analysis, there were 129 fifth and sixth-grade students and 129 eleventh and twelfth grade students. An informational sheet on the research project was sent home to the parents of each of the students (see Appendix A).

Settings, equipment, and materials

Settings. All of the experimental sessions were held in the students' schools. All settings were quiet, and relatively disruption-free.

Equipment. A projection screen, slide projector, and cassette recorder were used in each session.

Materials. Each session used one of four prepared 35mm slides (see Appendix B), pencils, audio tape containing the story narration, directions, and test questions (see Appendix C), and answer sheets (see Appendix D).

Procedures

There were four treatment groups. Each group viewed one of four treatment slides. The elementary and high-school students were randomly assigned, as a class unit, to one of four treatment groups. In these classes, students had been randomly assigned by the school system. Each treatment group was given an oral overview of the research project. Questions from the students were encouraged and answered at that time. Participants were given pencils and answer sheets. An audio tape containing the orientation story narration, test directions, and test questions was used. After the story narration was heard, each treatment group viewed one graph containing fictitious data presented on a 35mm slide. The same fictitious data, describing the incomes of various European merchants, was shown to each of the four groups in both the age groups. The treatment slides (from Head & Moore, 1989) were in one of the following graphic formats: 1) bar, 2) line, 3) table, 4) line-table combination. The data was fictitious to alleviate any effect of prior knowledge, and described various European merchants income during the middle ages. While viewing the graph, the students responded to the same 42 questions in three categories: specific amounts, static and dynamic comparisons of the data. The narration, data, and questions were developed by Washburne (1927) and revised by Head and Moore (1989). The order of the three types of questions were randomly placed and presented in the same order to all four treatment groups. The students were given 9 seconds to respond to each question.

Upon completion of the 42 questions, the students were asked to from a mental picture of the slide they had been viewing. They were given one additional minute to view the slide. The projector was then turned off and the students were asked to respond by giving numerical or verbal answers to 14 questions. Questions in this category were developed by expanding the original five questions developed by Head and Moore (1989). These questions paralleled the previous static and dynamic test questions. All students in all four treatments answered the same questions given in the same order. The students had 7 seconds to respond to each question.

Analyses of data

A 4 (Graph Type) X 2 (Age) X 2 (Gender) multivariate analysis of variance (MANOVA) with repeated measures for the four types of questions was planned and performed. The independent variables were type of graph (between), age (between), gender (between), and type of question (within). The dependent variable was the interpretation of quantitative information as measured by the test questions.

The analyses of simple interaction effects were performed due to the presence of interaction effects. These analyses allowed for the "teasing apart" of interactions.

RESULTS

The analysis of the data follow a 4 (Graph Type) X 2 (Age) X 2 (Gender) multivariate analysis of variance (MANOVA) with repeated measures for the four types of questions. The MANOVA was implemented to describe the relationships among the three independent variables, graph format, age, and gender and the dependent variable, the scores on each of the four types of questions, amount, static, dynamic, and recall.

In the analysis of main effects (see Table 1 for means), graph ($F(1,242)=5.54$, $MSe=11.49$), and age ($F(1,242)=75.80$, $MSe=11.49$) were statistically significant ($p<.001$). These main effects are qualified, however, by four interaction effects, for graph by question types ($F(9,726)=8.04$, $MSe=3.22$, $p<.001$), age by question types ($F(3,726)=9.21$, $MSe=3.22$, $p<.001$), graph by age by question types ($F(9,726)=4.64$, $MSe=3.22$, $p<.001$), and graph by gender by question types ($F(9,726)=1.86$, $MSe=3.22$, $p<.055$). Appendix E displays the summary of the multivariant analysis of variance for the between-subject effects and the within-subject effect. No further analysis of the main effects was conducted because of the nature of the interaction effects, which are the primary consideration of this study. Post-hoc analyses of the interactions were completed using the Simple Interactions Effects analysis.

The interaction, graph by question type, as seen in Figure 1. shows that high-school and elementary students scored higher on the amount ($F(3,664)=11.53$, $MSe=5.29$, $p<.01$) and static ($F(3,664)=9.39$, $MSe=5.29$, $p<.01$) questions when viewing the table graph ($\bar{X}=13.18$, $\bar{X}=12.18$), than the students viewing the three other graphs. Students scored higher on the

Table 1

Mean Scores of Question Types by Sex, Age, and Graph Type.

		MALE			FEMALE			
Graph	Question	HS	ELEM	TOT	HS	ELEM	TOT	GRTOT
Table	Amount	13.00	12.60	12.80	13.67	13.44	13.55	13.18
	Static	12.37	12.37	12.37	13.10	10.89	11.99	12.18
	Dynamic	10.84	8.10	9.47	10.91	5.78	8.34	8.91
	Recall	11.95	9.70	10.82	11.29	9.67	10.48	10.65
	TOTAL	12.04	10.69	11.37	12.24	9.95	11.09	11.23
	NUMBER	19	10	29	21	9	30	59
Line-table	Amount	12.93	11.21	12.07	12.58	9.86	11.22	11.50
	Static	11.80	9.57	10.69	12.53	8.57	10.55	10.62
	Dynamic	11.13	9.93	10.53	10.21	9.00	9.61	10.07
	Recall	11.73	10.93	11.33	12.05	11.29	11.67	11.50
	TOTAL	11.90	10.41	11.16	11.84	9.68	10.76	10.92
	NUMBER	15	14	29	19	7	26	55
Line	Amount	11.52	9.75	10.64	11.77	10.39	11.08	10.86
	Static	11.04	8.58	9.81	11.36	9.17	10.27	10.04
	Dynamic	10.13	8.50	9.32	10.36	7.44	8.90	9.11
	Recall	12.25	10.25	11.25	11.32	9.67	10.49	10.87
	TOTAL	11.24	9.27	10.26	11.21	9.17	10.19	10.22
	NUMBER	23	12	34	22	18	40	75
Bar	Amount	11.64	10.93	11.29	12.80	10.00	11.40	11.34
	Static	11.64	10.00	10.82	12.07	9.22	10.64	10.73
	Dynamic	10.27	6.07	8.17	10.73	7.17	8.95	8.56
	Recall	10.27	9.86	10.07	10.53	9.72	10.13	10.10
	TOTAL	10.96	9.22	10.09	11.53	9.03	10.28	10.18
	NUMBER	22	14	36	15	18	33	69
	TOTNUMBER	79	50	129	77	52	129	258

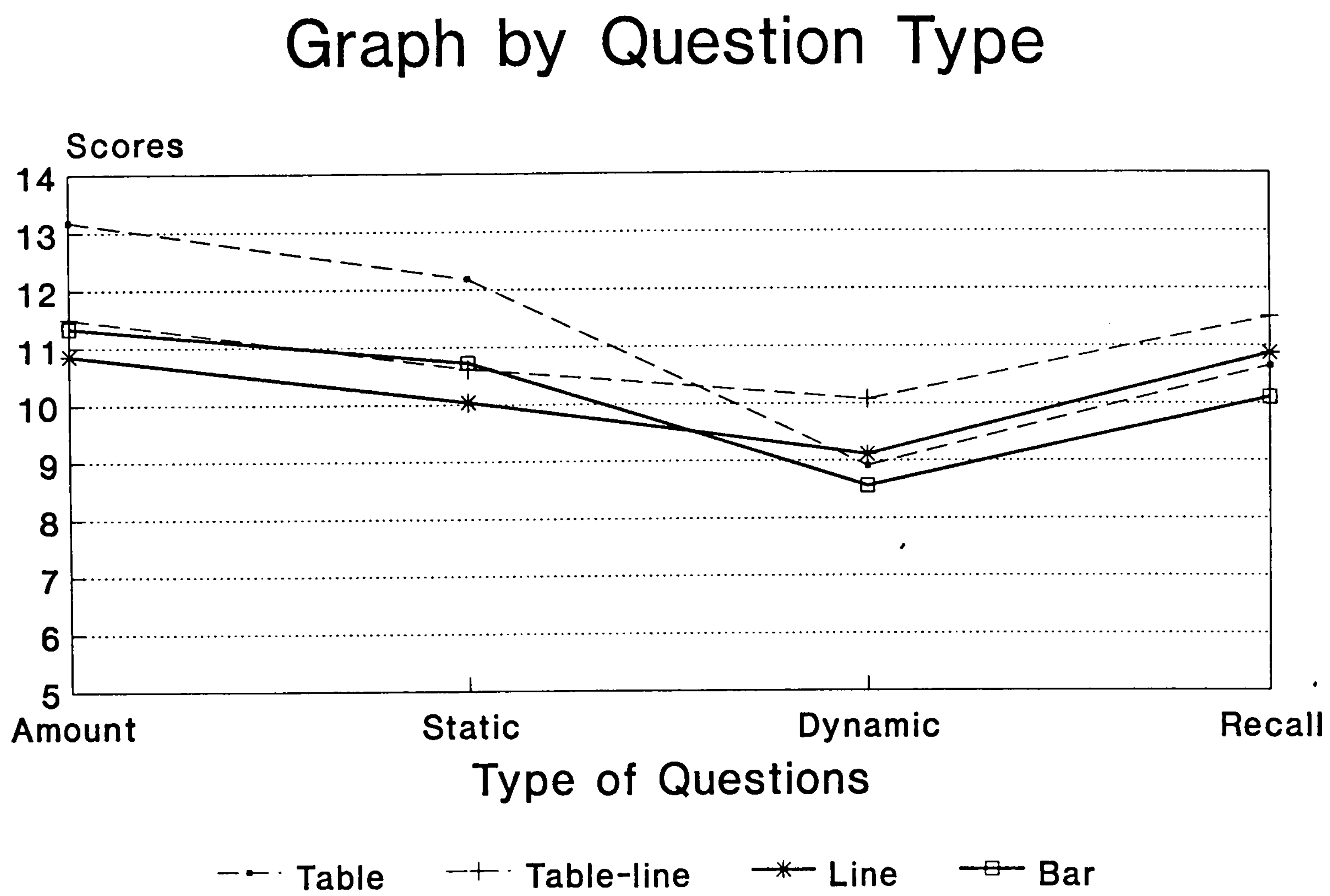


Figure 1. Total mean scores for high school and elementary students by graph type.

dynamic, ($F(3,664)=4.74$, $MSe=5.29$, $p<.01$) and recall, ($F(3,664)=4.08$, $MSe=5.29$, $p<.01$) questions, when viewing the line-table ($\bar{X}=10.07$, $\bar{X}=11.5$) and line graphs ($\bar{X}=9.11$, $\bar{X}=10.87$) than the students viewing the table or bar graphs. Appendix F shows the results of the simple interaction effects which show significant differences ($p<.01$) for scores on questions types depending on the type of graph viewed. These results, therefore, indicate a preference for graph type when interpreting amount, static, dynamic, and recall questions of numerical data.

The interaction, age by question type, as seen in Figure 2, shows that although the high-school students outperformed the elementary students for each question type, Amount, ($F(1,664)=27.91$, $MSe=5.29$, $p<.01$); Static, ($F(1,664)=60.88$, $MSe=5.29$, $p<.01$); Dynamic, ($F(1,664)=94.19$, $MSe=5.29$, $p<.01$); Recall, ($F(1,664)=20.29$, $MSe=5.29$, $p<.01$), the effect of age was not consistent across all question types. Appendix G shows the results of the simple interaction effects which display significant differences ($p<.01$) for age by question types. The difference in scores on the amount (HS, $\bar{X}=12.48$, Elem., $\bar{X}=11.02$) recall (HS, $\bar{X}=11.42$, Elem., $\bar{X}=10.13$) questions are closer together for the two age groups, than the scores on the static (HS, $\bar{X}=11.99$, Elem., $\bar{X}=9.8$) and dynamic (HS, $\bar{X}=10.57$, Elem., $\bar{X}=7.75$) questions. These results indicate developmental differences in the ability to interpret amount, static, dynamic, and recall questions of numerical data.

The three-way interaction, graph by age by question type, as seen in Figures 3a (high-school students) and 3b (elementary students) shows that the mean scores for each question type are closer together for the high-school students than those for the elementary students. This interaction indicates that

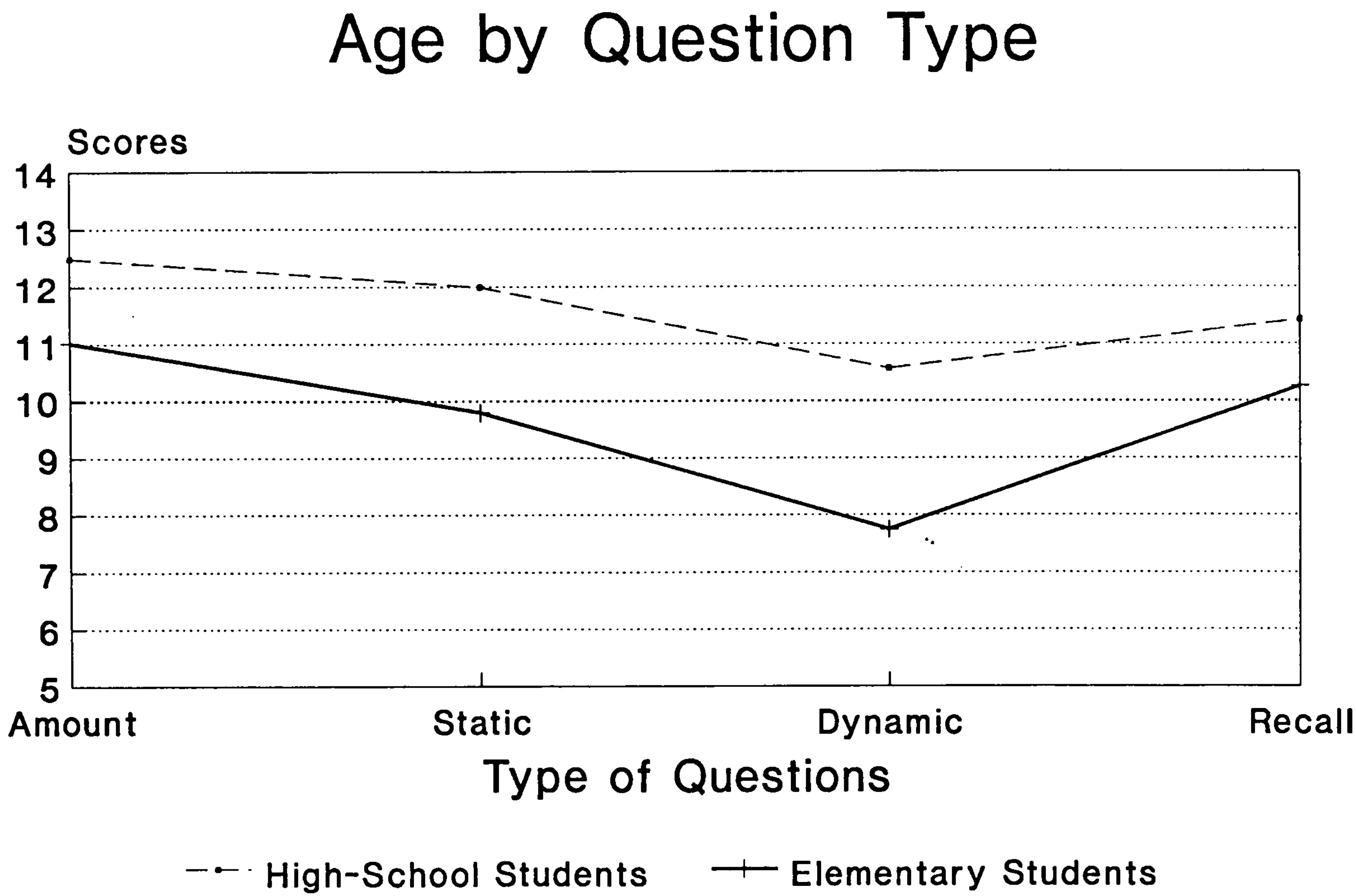


Figure 2. Total mean scores for high school and elementary students by age.

the graphic format best to interpret amount, static, dynamic, and recall questions for quantitative data is dependent on the age of the students.

An analysis of simple interaction effects indicate that high-school students' ability to interpret quantitative data for three types of questions, amount, static, and recall depends on the type of graph viewed. On the amount questions ($\underline{F}(3,664)=4.32$, $\underline{MSe}=5.29$, $\underline{p}<.01$), students interpreting the table graph had the highest scores ($\bar{X}=13.33$), while the students interpreting the line graph had the lowest scores ($\bar{X}=11.65$). On the static questions ($\underline{F}(3, 664)=3.39$, $\underline{MSe}=5.29$, $\underline{p}<.05$), students viewing the table graph also scored the highest ($\bar{X}=12.73$). On dynamic questions ($\underline{F}(3,664)=1.67$, $\underline{MSe}=5.29$, $\underline{p}>.05$), the students did equally well using any of the four graphs. The bar graph ($\bar{X}=10.4$) was the least effective for answering the recall questions ($\underline{F}(3,664)=3.10$, $\underline{MSe}=5.29$, $\underline{p}<.05$).

Simple interaction effects indicate that elementary students' ability to interpret quantitative data for three types of questions, amount, static, and dynamic depends on the type of graph viewed. On the amount ($\underline{F}(3,664)=6.91$, $\underline{MSe}=5.29$, $\underline{p}<.01$), and the static ($\underline{F}(3,664)=5.42$,.$\underline{MSe}=5.29$, $\underline{p}<.01$) questions, the students viewing the table graph had the highest scores ($\bar{X}=13.02$, $\bar{X}=12.73$, respectively). This is the same for the high-school students. Elementary students using the line-table graph ($\bar{X}=9.46$) and the line graph ($\bar{X}=7.97$) to answer dynamic questions ($\underline{F}(3,664)=7.52$, $\underline{MSe}=5.29$, $\underline{p}<.01$) achieved the highest scores ($\bar{X}=9.46$). For the high-school students, no graph emerged as statistically superior for the dynamic questions. On recall questions ($\underline{F}(3,664)=1.67$, $\underline{MSe}=5.29$, $\underline{p}>05$), the elementary students did equally well

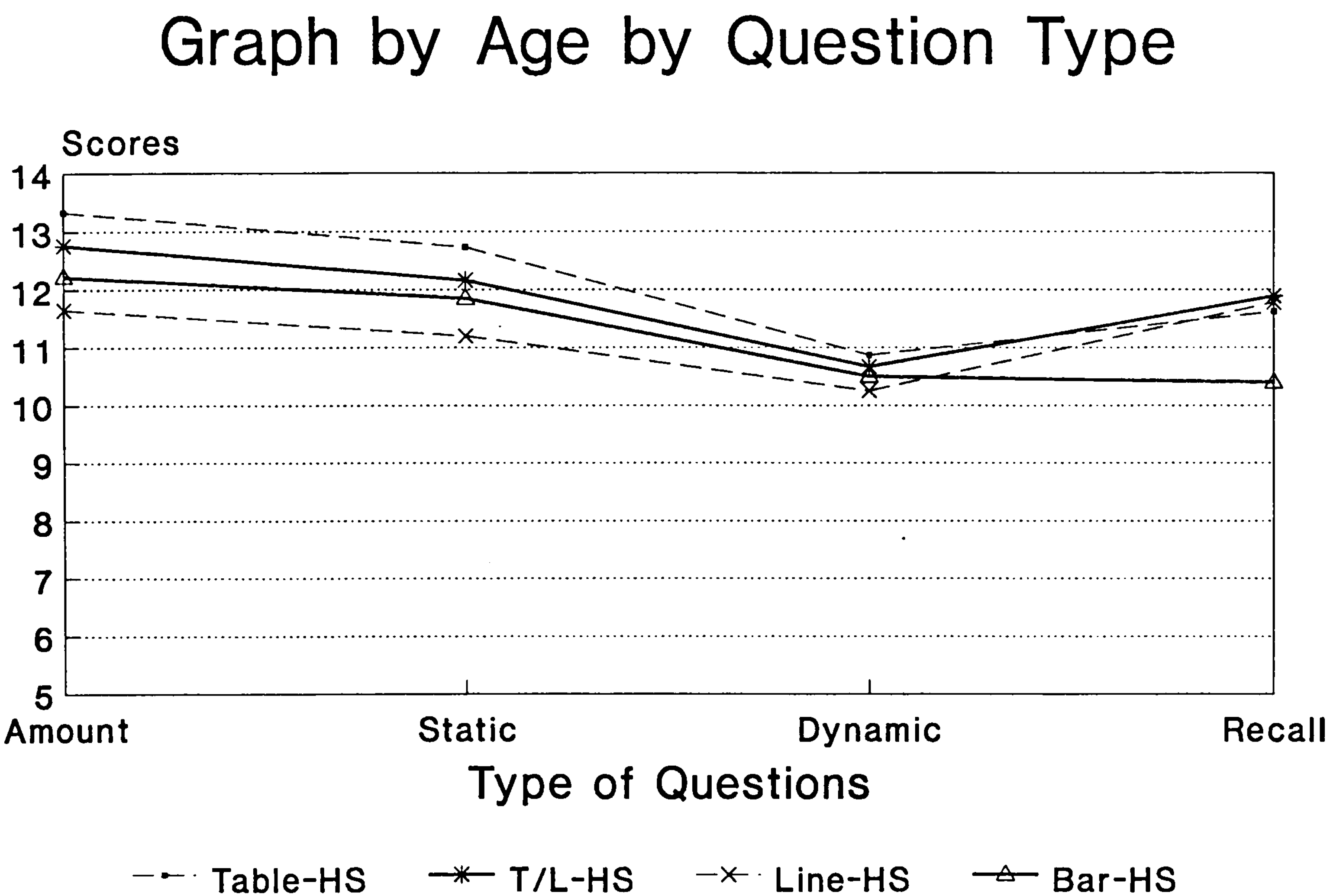


Figure 3a. Mean scores of high-school students on questions by graph type.

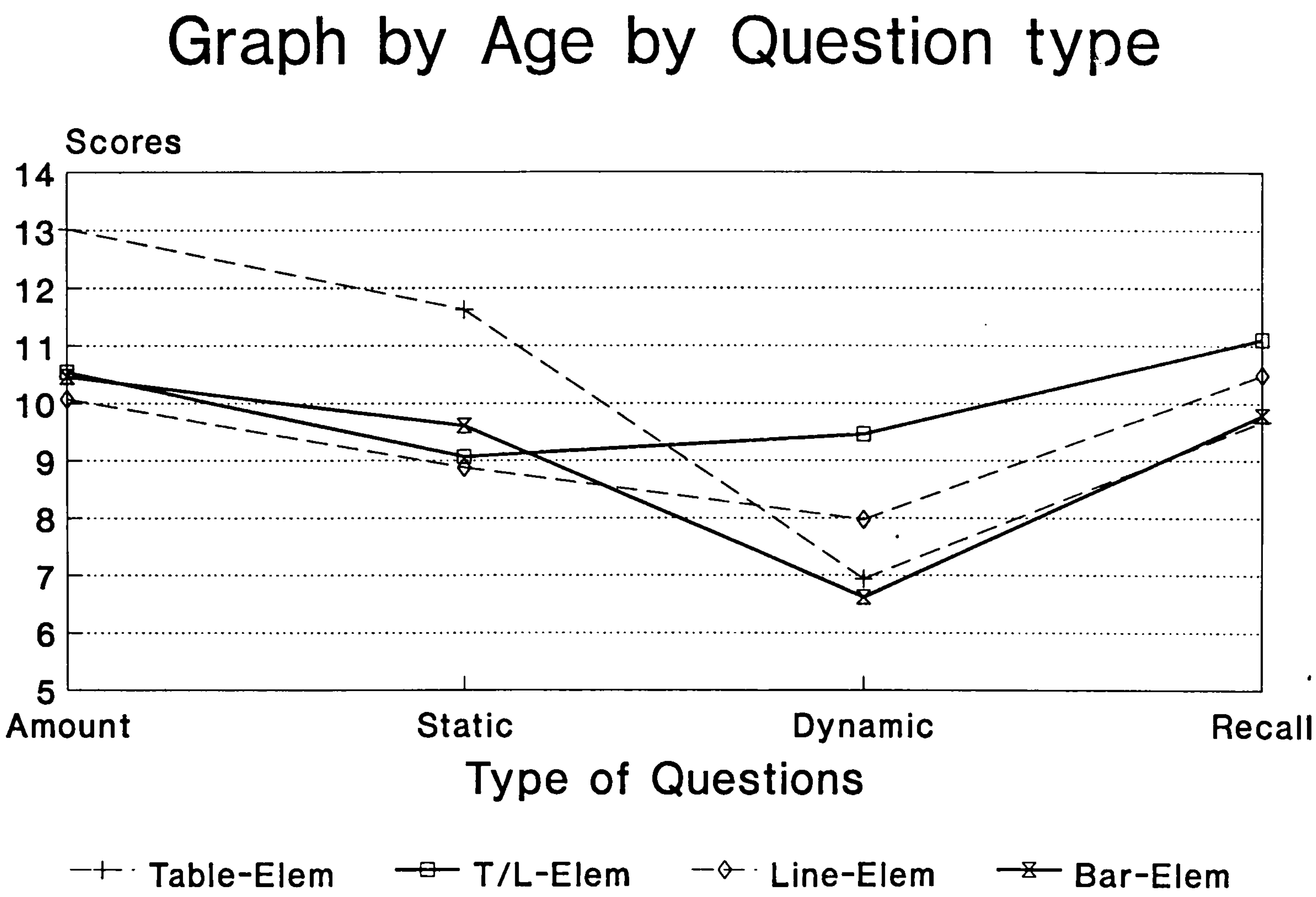


Figure 3b. Mean scores of elementary students on questions by graph type.

using any of the four graphs. Appendix H shows the simple interactions effects for the elementary students.

The three-way interaction, graph by gender by question type, as seen in Figure 4a (males) and Figure 4b (females) show that there are gender differences in ability to use graphic formats to interpret numerical data.

For the male students, the ability to interpret quantitative data for three types of questions, amount, static, and dynamic, is dependent on type of graph. These participants when viewing the table graph had the highest scores ($\bar{X}$ =12.8, $\bar{X}$ =12.37) on the amount ($F(3,664)=4.37$, $MSe=5.29$, $p<.01$) and static ($F(3,664)=4.51$, $MSe=5.29$, $p<.01$) questions. For the dynamic questions ($F(3,664)=2.95$, $MSe=5.29$, $p<.01$) the interpretation of the line-table graph produced the highest scores ($\bar{X}$ =10.53). Students did equally well on the recall questions ($F(3,664)=2.31$, $MSe=5.29$, $p>.05$) no matter what graph they viewed. Appendix I shows the simple interaction effects for male participants.

For the female students, the ability to interpret quantitative data for three types of questions, amount, static, and recall is dependent on type of graph. Similar to the males, the females, when viewing the table graph, had the highest scores ($\bar{X}$ =13.55, $\bar{X}$ =11.99) on the amount ($F(3.664)=7.70$, $MSe=5.29$, $p<.01$) and static ($F(3,664)=5.61$, $MSe=5.29$, $p<.01$) questions. On the recall questions, these students achieved the highest scores ($\bar{X}$ =11.67) when viewing the line-table, which differs from the males where no graph emerged as superior. Female students did equally well on the dynamic questions no matter what graph they were viewing ($F(3,664=1.22$, $MSe=5.29$, $p>.05$). This finding is in contrast to the males viewing the line-table graph who produced the highest scores ($p<.01$). Simple interaction effects are summarized in Appendix J.

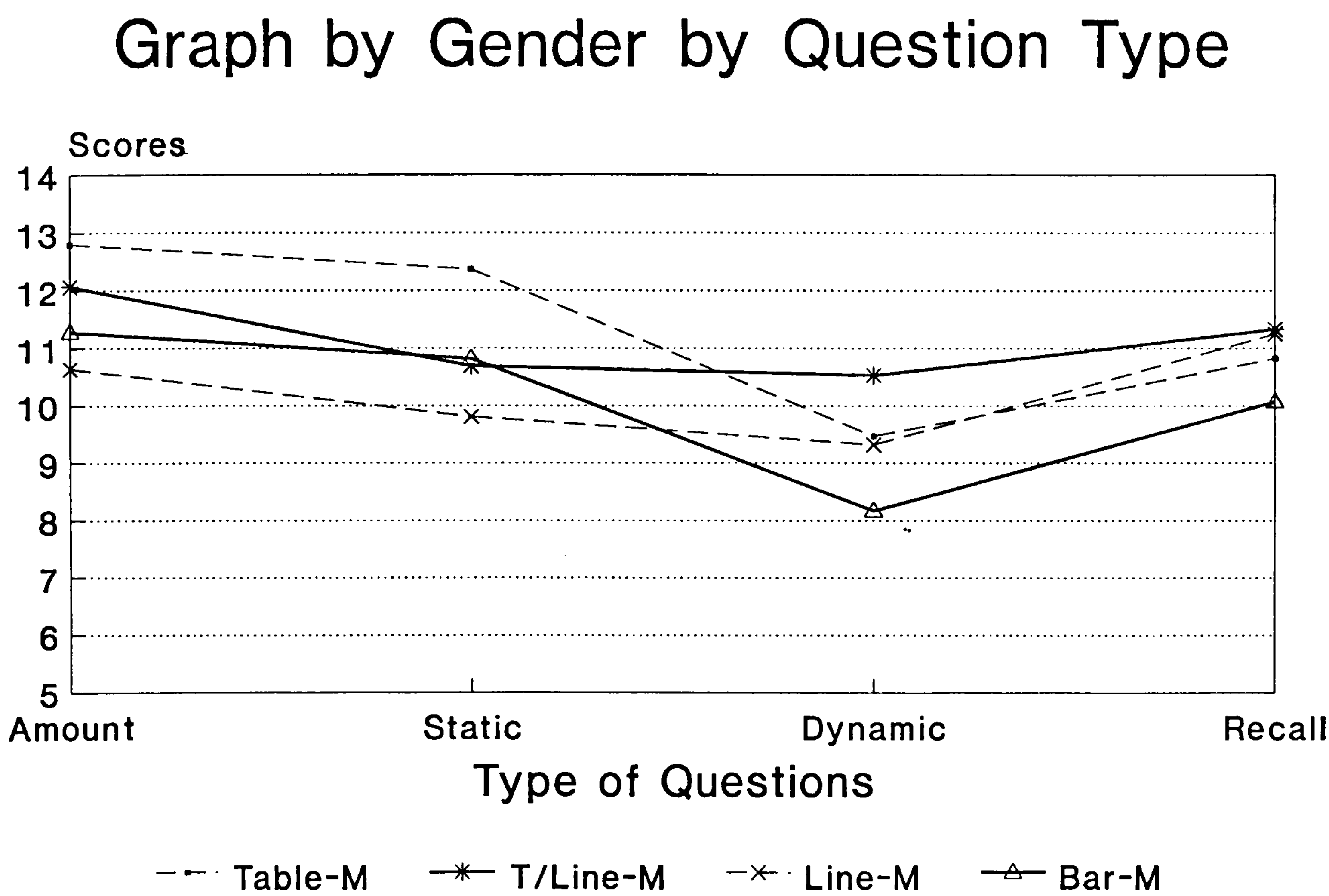


Figure 4a. Mean scores of male students on questions by graph type.

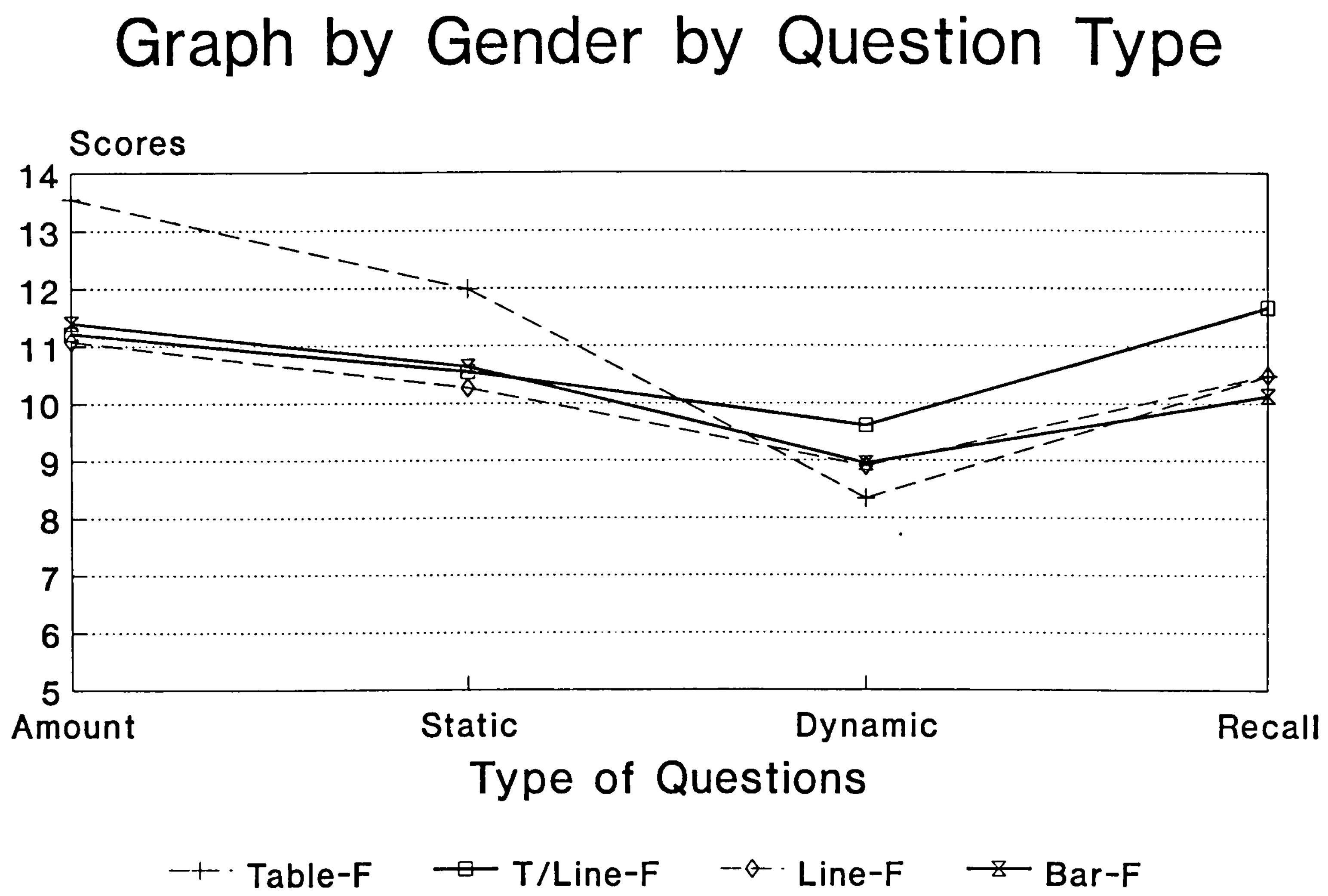


Figure 4b. Mean scores of female students on questions by graph type.

CONCLUSIONS

The study was designed to investigate the interpretation of numerical data when presented in several different graphic formats to different age groups and sexes. The findings indicate that graphic format, age, and gender do affect the ability to interpret numerical data. These findings support the results of Head and Moore (1989), that certain graphs are more effective presentations of data in terms of students' ability to answer certain types of questions. Specifically, the results lend support to their conclusions that table graphs are the most effective graph for amount and static questions, while line graphs are the least effective for amount, static and dynamic questions. In order to completely analyze the results, each analysis is discussed separately by research question.

Interaction of Age and Types of Questions

The interaction between age and question types, indicated that high school students scored higher than elementary students on all four questions. This is a predictable result based on both the information-processing model (e.g., Anderson, 1985; Gross, 1985; Flavell, 1985) and Piagetian theory (e.g., Anderson, 1985; Phillips, 1969), which support the concept that ability to use memory efficiently increases with age. Even though the mean scores for each question were different for both age groups, a pattern of correct responses was established. This pattern clarified the order of difficulty for questions, from lowest to highest, to be amount, static, recall, and dynamic. The difference in mean scores between the two age groups is larger for the two more difficult questions: static and dynamic. The static questions required the students to do comparisons in a given year, and the dynamic questions required the students to scan across the years. In comparison, the amount questions required only a reading of one dimension on any of the graphs. These findings are supported by Gross (1985) and Finkle (1973) who found that young children have difficulty concentrating on more than one dimension at a time. The closer mean scores between the two age groups in the recall questions is more difficult to explain, because the majority of these questions require the students to make comparisons across the entire time span of the experiment. Thus, this type of question would demand a more sophisticated strategy in order to answer correctly, yet the means for the two groups are closer together than the means for the static and dynamic questions. One explanation would be that both groups were aided in answering these questions, because of the one-minute time period given to examine the graph before the recall questions began. In this case, both age groups could familiarize themselves with the graph in preparation for answering additional questions (e.g., Anderson, 1985). The developmental difference, that older students are able to process the quantitative data more efficiently than the younger students emerged as a predictable result (e.g., Flavell, 1985; Gross, 1985; Piaget, 1952; Siegler, 1981).

Interaction of Graph and Type of Questions

The interaction between graph formats and types of questions indicate that certain graphs are better for answering certain types of questions. The table graph was better for answering amount and static questions, while the line-table graph was better for answering dynamic and recall questions. The students viewing the line graph received the lowest scores on the amount and static questions, but then recovered for the dynamic and recall questions, scoring the next highest scores to the line-table graph. The line graph results for dynamic and recall questions is supported by Heinich, Molenda, and Russell

(1985) and Griffin (1988). They proposed that line graphs be used when data covers a long period of time with the emphasis on trends, estimates, and interpolations of the data. The efficiency of the table graph for the amount and static questions is consistent with the findings of Head and Moore (1989). The students viewing the bar graph had lower scores for all types of questions, but did score the second highest on the static questions. This finding is confirmed by Griffin's (1988) recommendation that bar graphs be used to compare or contrast a specific amount between one period and the next. Yet, it is in contradiction to his point that bar graphs can emphasize the amount of data in a series, since students received lower scores on the amount questions when viewing this graph. A point could be made that the efficiency of the line-table graph for the dynamic and recall questions may be due to its line dimension, since the students viewing the table graph scored lower on the dynamic and recall questions, while the line treatment students scored the second highest on these two types of questions. Findings from this study and the study completed by Head and Moore (1989), suggest that there are preferred graphic formats to use to interpret amount, static, dynamic, and recall questions of quantitative data.

Interaction of Graph, Age and Types of Questions

The three-way interaction between graph, age, and types of questions indicate that selection of graph format is relevant to the age of the participant and the type of question. The previous discussion took into account all scores for all participants, therefore providing a global view of graphs and types of questions. The three-way interaction analysis is able to tease apart the independent variables so that an expanded explanation for age groups can be derived from this study's results.

High-school students' scores on the amount, static, and recall questions depend on the viewing of a particular graph. The table graph was the most efficient graph for these older students to use to answer amount and static questions. Macdonald-Ross (1977) suggest a table graph has a compact format, thereby, enabling easy access to data for answering questions on a single dimension. Head and Moore (1989) suggest the success of the table graph is due to the limited number of data points, and therefore, the table provides easy readability for amount and static questions. Students did equally well on dynamic questions no matter which graph they were viewing. This result is similar to Head and Moore's results, in that no graph emerges as more effective, and that the students viewing the line and bar score the lowest on the questions. The literature (e.g., Griffin, 1988; Macdonald-Ross, 1977) suggests the use of line and bar graphs to compare data across more than one dimension, yet this study, like Head and Moore did not support this premise. On the recall question, the bar graph was the least effective. Head and Moore suggest that the failure of the line and bar graph to be superior on the dynamic and the recall questions may be due to the small amount of data, therefore, enabling the other graphs to be used just as, or even more efficiently, than these two types of graphs.

Elementary-school students' scores on the amount, static, and dynamic questions depend on the viewing of a particular graph. The table graph was the most efficient graph for these students to use to answer amount and static questions, which is the same as the older students. On recall questions, these students did equally well using any of the four graphs. Again these results are similar to the high-school students who used all but the bar graph equally well to answer these questions. On the dynamic question, the elementary students in the treatment groups of either the line-table or the line graphs conditions scored higher on these questions. Younger children, who are not able to process information as quickly and as efficiently as older children (Sheingold, 1973) may have found these graphs easier to process due to their spatial nature which illustrates variations on at least two dimensions (Griffin, 1985; Macdonald-Ross, 1977).

These findings indicate that the ability to process information more quickly by older students (Cowan, Suomi, & Morse, 1982; Lasky & Spiro, 1980; Welsandt & Meyer, 1974) enabled them to utilize the attributes of several graphs more effectively than the younger students. The simplicity of easily reading the data from the table and determining relationships among the year categories seemed to help the younger students in answering the amount and static questions. The more complex nature of the other graphs would have required more processing skill, which the high-school students could have handled more easily. Lange (1973) and Vaughan (1968) suggested that organizational techniques seem to demonstrate developmental trends. This explanation would also be supported by Larkin and Simon (1987), who proposed that if two representations are informationally equivalent, their computational efficiency depends on the information-processing operators in use. The information-processing model suggests that as an individual acquires more skill or experience in processing information the more efficient is their ability to solve problems (Magliaro, 1988). For the high-school students their added experience in recognizing patterns enabled them to organize perceptual features (cues) so that relevant knowledge from LTM is activated. Bruner, Goodnow, and Auston (1967) stated that individuals tend to focus attention on cues that have been helpful in the past. Their ability to focus their attention would increase high-school students' computational efficiency over that of the elementary school students.

The speed and accuracy of retrieval of information from long-term memory is directly dependent on how the information was encoded and the attention being given to the stimulus (Anderson, 1985; Klatzky, 1980). As already pointed out, younger students have more difficulty maintaining attention to relevant details. Due to the time limit (9 seconds) to answer each question, the younger students may have found it more difficult to process the information in such a short time. When working with the elementary-school children, many verbalized that they didn't have enough time to find the answer before the next question began.

Interaction of Graph, Gender, and Type of Question

The three-way interaction of graph, gender, and type of question indicates that two types of questions, dynamic and recall have different efficacy for the two sexes. The range of difficulty for both groups from highest to lowest was the same, dynamic, static, recall, and amount. For dynamic questions, males' scores depended on the type of graph they used, while females did not. Both groups scored higher using the line-table graph, but the males' scores were significantly higher, while the females were not. The dynamic question required scanning across the years which could favor a spatial orientation, as found in the line-table graph and which the research has also indicted is usually a more developed skill among males (Maccoby & Jacklin, 1974; Thomas & Jamison, 1975). It could be argued that the recall questions also required spatial positioning. The female participants utilized the line-table graph to score statistically higher on the recall questions then with any other graph. The males did not differ on recall as a function of graph type. These results do not support the research findings that indicate the superiority of males over females in spatial-visualization.

Summary

In analyzing the selection of the "right" graphic format to present quantitative data, several indications can be derived from this study. First, the table graphs are effective means for answering amount and static questions. As the questions become more complex, such as in a dynamic question, then the table graph is one of the least effective means of graphic communication. Second, in recall, the indication is that the line-table format and then the line format may be the most effective graph to use. Third, an age difference emerged, as did a gender difference for particular graphs.

To suggest implications for utilizing the "right" graphic format, the presenter's goal for displaying the quantitative data has to be analyzed. If the presentation wants the audience to leave the presentation remembering a visual image and understanding of the data, then the line-table seems to be the most effective over all groups, ages and sexes. Yet if the presenter's purpose is for the audience to quickly analyze data and locate certain points, then the table graph is the most effective. An important point made by Head and Moore (1989) is that the data set is relatively small with only 24 data points. A larger set may give less advantage to the table graph and more advantage to a more spatial-oriented graph such as the line or bar graph. This would be supported by Larkin and Simon's (1985) work which indicates diagrams are more efficient means to communicate complicated information.

High-school students can interpret and encode quantitative data in graphic format with relative ease as demonstrated by their high means in this study. Younger students have a more difficulty time. Further research into effective graphic communication for younger students is needed.

Male performances on the visual interpretation task was not superior to the female performances. This was not a predictable result since much of the literature indicates a stronger spatial visualization skill for the male.

References

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), The psychology of learning and motivation: Advances in Research Theory (Vol. 2). New York: Academic Press.

American National Standards Institute (1979). Time-series charts, New York: The American Society of Mechanical Engineers.

Anderson, J. R. (1978). Arguments concerning representations for mental imagery. Psychological Review, 85, 249-277.

Anderson, J. R., & Bower, G. H. (1973). Human associative memory. Washington, D. C.: Winston.

Anderson, R. C., Greeno, J. G., Kline, P. J. & Neves, D. M. (1981). Acquisition of problem solving skill. In J. R. Anderson (Ed.), Cognitive skills and their acquisition. Hillsdale, NJ: Erlbaum.

Anderson, R. C. (1968). Part versus whole task procedures for teaching. Journal of Educational Psychology, 56, 283-294.

Anderson, J. R. (1985). Cognitive psychology and its implications. New York: Freeman.

Baddeley, A D., Grant, S., Wight, E., & Thomson, N. (1975). Imagery and visual memory. In P. M. Rabbitt and S. Dornic (Eds.), Attention and performance (Vol. 5). New York: Academic Press.

Bartlett, F. C. (1958). Thinking. New York: Basic Books.

Belmont, J. M. (1972). Relations of age and intelligence to short-term color memory. Child Development, 43, 19-29.

Bertin, J. (1973). Semiology of graphics (W. Berg, Trans.). Madsion, Wisconsin: The University of Wisconsin. (Original work published in 1967)

Boswell, S. L. (1979). Sex roles, attitudes and achievement in mathematics:A study of elementary school children and Ph.D's. Paper presented as part of a Symposium on Gender Differences in Participation in Mathematics at The Society for Research in Child Development, San Francisco.

Bovy, R. (1983, April). Defining the psychology of active features of instructional treatments designed to facilitate cue attendance. Paper presented at the meeting of the American Educational Research Association, Montreal.

Brinton, W. C. (1914). Graphic methods of presenting facts. New York: Engineering Magazine.

Broadbent, D. E. (1958). Perception and communication. New York: Pergamon Press.

Brown, R. M. (1977). An examination of visual and verbal coding processes in preschool children. Child Development, 48, 38-45.

Bruner, J. S., Goodnow, J.J., & Auston, G. A. (1967). A study of thinking. New York: John Wiley & Sons, Inc.

Brush, L. R. (1979). Why women avoid the study of mathematics: A longitudinal study. Report to the National Institute of Education, Abt Associates, Inc., Cambridge, Massachusetts.

Calvert, S. L., Huston, A. C., Watkins, B. A., & Wright, J. C. (1982). The relation between selective attention to television forms and children's comprehension of content. Child Development, 53, 601-610.

Cantor, J. S., & Spiker, C. C. (1978). The problem-solving strategies of kindergarten and first-grade children during discrimination learning. Journal of Experimental Child Psychology, 26, 341-358.

Case, R. (1978). Intellectual development from birth to adulthood: A neo-Piagetian approach. In R. S. Siegler (Ed.), Children's thinking: What develops?. Hillsdale, NJ: Lawrence Erlbaum Associates.

Chi, M. T. H. (1976). Short-term memory limitations in children: Capacity or processing deficits?. Memory and Cognition, 4, 559-572.

Chi, M. T. H. (1978). Knowledge structures and memory development. In R. S. Siegler (Ed.), Children's thinking: What develops?. Hillsdale, NJ: Lawrence Erlbaum Associates.

Cleveland, W. S. & McGill, R. (1984). Graphical perception: Theory, experimentation, and application to the development of graphical methods. Journal of the American Statistical Association. 79, 531-554.

Cochran, L. M., Younghouse, P., Sorflaten, J., & Morlek, R. (1980). Exploring approaches to researching visual literacy. Educational Communications and Technology Journal. 28, 243-266.

Collins, A. M., & Quillian, M. R. (1969). Retrieval time from semantic memory. Journal of Verbal Learning and Verbal Behavior, 8, 240-247.

Cowan, N., Soumi, K., & Morse, P. A. (1982). Echoic and storage in infant perception. Child Development, 53, 984-990.

Cramer, P. (1976). Changes from visual memory organization as a function of age. Journal of Experimental Child Psychology, 22, 50-57.

Croxton, F. E. (1927). Further studies in the graphic use of circles and bars. Journal of the American Statistical Association, 27, 54-60.

Dale, E. (1946). Audio-Visual Methods in Teaching. New York: Holt, Rinehart, and Winston.

Doyle, A. (1973). Listening to distraction: A developmental study of selective attention. Journal of Experimental Child Psychology, 15, 100-115.

Dwyer, F. M. (1978). Strategies for Improving Visual Learning. State College, Penn.: Learning Services.

Eells, W. C. (1926). The relative merits of circles and bars for representing components parts. Journal of the American Statistical Association, 21, 119-132.

Eimas, P. D., & Miller, J. L. (1980). Discrimination of information for manner of articulation. Infant Behavior and Development, 3, 367-385.

Farnham-Diggory, S. (1972). Information processing in children. New York: Academic Press.

Finkle, D. L. (1973). A developmental comparison of the processing of two types of visual information. Journal of Experimental Child Psychology, 16, 250-266.

Flavell, J. H. (1970b). Developmental studies of mediated memory. In H. W. Reese & L. P. Lipsitt (Eds.), Advances in child development and behavior (Vol. 5). New York: Academic Press.

Flavell, J. H. (1985). Cognitive development. Englewood Cliffs, New Jersey: Prentice-Hall, Inc.

Flavell, J. H., Beach, D. R., & Chinsky, J. M. (1966). Spontaneous verbal rehearsal in memory tasks as a function of age. Child Development, 37, 283-289.

Geffen, G., & Sexton, M. A. (1978). The development of auditory strategies of attention. Development Psychology, 14, 11-17.

Gholson, B., Levine, M., & Phillips, S. (1972). Hypotheses, strategies, and stereotypes in discrimination learning. Journal of Experimental Child Psychology, 13, 423-446.

Griffen, R. E. (1988, October). Using graphs correctly: What are the basic elements in the language of graphs. Paper presented at the annual meeting of the International Visual Literacy Conference, Blacksburg, Virginia.

Gross, T. F. (1985). Cognitive development. Monterey, Calif.: Brooks/Cole Publishing Company.

Hartup, W.W. & Zook, E. A. (1960). Sex-role preferences in three and four-year-old children. Journal of Consulting Psychology, 24, 420-426.

Hayes, D. S., & Rosner, S. R. (1975). The phonetic effect in preschool children: The influence of overt rehearsal and verbal instructions. Journal of Experimental Child Psychology, 20, 391-399.

Head, J. T., & Moore, D. M. (1989, February). The effect of graphic format on the interpretation of quantitative data. Paper presented at the annual meeting of the Association for Educational Communication and Technology Annual Conference, Dallas, Texas.

Heinich, R., Molenda, M., & Russell, J. D. (1985). Instructional media and the new technologies of instruction. New York: John Wiley & Sons.

Hiscock, M., & Kinsbourne, M. (1980). Asymmetries of selective listening and attention switching in children. Developmental Psychology, 16, 70-82.

Huston, A. C. (1983). Sex-typing. In P. H. Mussen (Ed.), Handbook of child psychology. New York: John Wiley & Sons.

Kail, R. (1979). The development of memory in children. San Francisco: W.H. Freeman.

Keeney, T.J., Cannizzo, S. R., & Flavell, J. H. (1967). Spontaneous and induced verbal rehearsal in a recall task. Child Development, 38, 953-966.

Kellas, G., McCauley, C., & McFarland, C. E. (1975). Developmental aspects of storage and retrieval. Journal of Experimental Child Psychology, 19, 51-62.

Klahr, D. (1980). Information-processing models of intellectual development. In R. H. Kluwe & H. Spada (Eds.), Developmental models of thinking. New York: Academic Press.

Klatsky, R. L. (1980). Human memory: Structures and processes. New York: Freeman.

Kosslyn, S. M. (1975). Information representation in visual images. Cognitive Psychology, 7, 341-370.

Kosslyn, S. M., Ball, T. M., & Reiser, B. J. (1978). Visual images preserve metric spatial information: Evidence from studies of image scanning. Journal of Experimental Psychology: Human Perception and Performance, 4, 47-60.

Kosslyn, S. M. & Pomerantz, J. R. (1977). Imagery, propositions, and the form of internal representations. Cognitive Psychology, 9, 52-76.

Lane, D. M. & Presson, D. A. (1982). The development of selective attention. Merrill-Palmer Quarterly, 28, 317-337.

Lange, G. (1973). The development of conceptual and rote recall skills among school-age children. Journal of Experimental Child Psychology, 15, 394-407.

Larkin, J. H. & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. Cognitive Science, 11, 65-99.

Lasky, R. E., & Spiro, D. (1980). The processing of tachistoscopically presented visual stimuli by five-month-old infants. Child Development, 51, 1292-1294.

Levie, W. L. (1987). Research on pictures: A guide to the literature. In D. M. Willows & H. A. Houghton (Eds.) The psychology of illustration. New York: Springer-Verlag.

Liben, L.S. (1979). Free recall by deaf and hearing children: Semantic clustering and recall in trained and untrained persons. Journal of Experimental Psychology, 27, 105-119.

Maccoby, E. E., & Jacklin, C. N. (1974). The psychology of sex differences. Stanford, Calif.: Stanford University Press.

Macdonald-Ross, M. (1977). How numbers are shown: A review of research on the presentation of quantitative data in texts. A V Communication Review, 25, 359-410.

Magliaro, S. (1988). Expertise in problem identification: A descriptive analysis of the cue selection and hypothesis generation of reading diagnosticians. Unpublished doctoral dissertation, Virginia Polytechnic Institute & State University, Blacksburg.

Mandler, G. (1967). Organization and memory. In K. W. Spence & J. T. Spence (Eds.), Psychology of learning and motivation (Vol. 1). New York: Academic Press.

Miller, G. A. (1953). What is information measurement? American Psychologist, 17, 748-762.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. Psychological Review, 63, 81-97.

Neisser, U. (1967). Cognitive psychology. New York: Appleton-Century-Crofts.

Nelson, K., & Kosslyn, S. M. (1975). Semantic retrieval in children and adults. Developmental Psychology, 11, 807-813.

Newell, A., & Simon, H. A. (1972). Human problem solving. Englewood Cliffs, NJ: Prentice-Hall.

Novak, J. D. (1979). Applying psychology and philosophy to the improvement of laboratory teaching. American Biology Teacher, 41, 466-470.

Paivio, A. (1971). Imagery and verbal processes. New York: Holt, Rinehart & Winston.

Paivio, A. (1986). Mental representations: A dual coding approach. New York: Oxford University Press.

Peterson, C. R. & Peterson, M. J. (1959). Short-term retention of individual verbal items. Journal of Experimental Psychology, 58, 193-198.

Phillips, J. L. (1969). The origins of intellect: Piaget's theory. San Francisco: W. H. Freeman & Company.

Piaget, J. (1952). The origins of intelligence in children (M. Cook, Trans.). New York: International Universities Press. (Original work published 1936).

Piaget, J. (1954). Construction of reality in the child (M. Cook, Trans.). New York: Basic Books, Inc. (Original work published 1937).

Piaget, J. (1951). Play, dreams, and imitation of childhood (C. Gattegno & F. M. Hodgson, Trans.). New York: W.W. Norton & Co. (Original work published 1945).

Posner, M. I. (1964a). Information reduction in the analysis of sequential tasks. Psychology Review, 71, 491-504.

Posner, M. I. (1969). Abstraction and the process of recognition. In J. T. Spence and G. H. Bower (Eds.), Advances in learning and motivation, (Vol. 3). New York: Academic Press.

Pressley, M. & Miller, G. (1987). Effects of illustrations on children's listening comprehension and oral prose memory. In D. M. Willows & H. A. Houghton (Eds.), The psychology of illustration. New York: Springer-Verlag.

Pylyshyn, Z. (1981). The imagery debate: Analogue media versus tacit knowledge. Pychological Review, 88, 16-45.

Reed, S. K. (1985). Effect of computer graphics on improving estimates to algebra word problems. Journal of Educational Psychology, 77, 285-298.

Reese, H. W. (1970). Imagery and contextual meaning. Psychological Bulletin, 73, 404-414.

Rohwer, W. D. Jr. (1970). Images and pictures in children's learning: research results and educational implications. Psychological Bulletin, 73, 393-403.

Rosner, S. R. (1971). The effect of rehearsal and chunking instructions on children's multi-trial free recall. Journal of Experimental Child Psychology, 11, 93-105.

Rosner, S. R., & Lindsay, D. T. (1974). The effects of retention interval on preschool children's short-term memory of verbal items. Journal of Experimental Child Psychology, 18, 72-80.

Salomon, G. (1974). Internalization of filmic schematic operations in interaction with learners' attitude. Journal of Educational Psychology, 66, 499-511.

Schmid, C. F. & Schmid, S. E. (1979). Handbook of graphic presentation. New York: John Wiley & Sons.

Shepard, R. N. (1967). Recognition memory for words, sentences, and pictures. Journal of Verbal Learning and Verbal Behavior, 6, 156-163.

Sheingold, K. (1973). Developmental differences in intake and storage of visual information. Journal of Experimental Child Psychology, 16, 1-11.

Siegler, R. S. (1981). Developmental sequences within and between concepts. Monographs of the Society for Research in Child Development, 46 (No. 2).

Sless, D. (1981). Learning and visual communication. New York: Wiley.

Steel, L., & Wise, L. L. (1979). Origins of sex differences in high school mathematics achievement and participation. Paper presented at the Convention of the American Educational Research Association, San Francisco.

Stein, A. H. (1971). The effects of sex-role standards for achievement and sex-role preference on three determinants of achievement motivation. Developmental Psychology, 4, 219-231.

Takeuchi, H. & Schmidt, A. H. (1980). New promise of computer graphics. Harvard Business Review, 58, 122-132.

Thomas, H., & Jamison, W. (1975). On the acquisition of understanding that still water is horizontal. Merrill-Palmer Quarterly, 21, 31-44.

Tufte, E. (1983). The visual display of quantitative information. Cheshire, Conn.: Graphic Press.

Vaughan, M. E. (1968). Clustering, age, and incidental learning. Journal of Experimental Child Psychology, 6, 323-325.

Waller, R. (1981, April). Understanding network diagrams. Paper presented at the annual meeting of the American Educational research Association, Los Angeles. (ERIC Document Reproduction Service No. 226-695).

Washburne, J. N. (1927a). An experimental study of various graphic, tabular, and textual methods of presenting quantitative material. Part 1: Journal of Educational Psychology, 18, 361-376.

Washburne, J. N. (1927b). An experimental study of various graphic, tabular, and textual methods of presenting quantitative material. Part 11: Numerals and written numerals. Journal of Educational Psychology, 68, 71-75.

Welsandt, R. F. & Meyer, P.A. (1974). Visual masking, mental age, and retardation. Journal of Experimental Child Psychology, 18, 512-519.

Winn, B. (1987). Charts, graphs, and diagrams in educational materials. In D. M. Willows & H. A. Houghton (Eds.) The psychology of illustration. New York: Springer-Verlag.

APPENDICES

APPENDIX A

Letter to parents

School's Letterhead

Dear Parents:

We are preparing a project on visual teaching materials in cooperation with the College of Education at Virginia Tech. This project will help us understand how children in middle childhood and adolescence interpret information when it is presented visually. We are asking students who are 10 and 11 years old and students who are 16 and 17 years old to participate.

Each student will be involved in one group session for approximately 45 minutes. In this session, students will be shown one graph, such as a bar or line graph, and then asked to respond to several questions concerning the information on the graph. On the answer form they will also indicate their age and if they are a boy or girl. Our experience has been that most students enjoy participating in projects of this kind.

We respect the right of the parent and of the student to withdraw from the project at any time. No one will be forced to participate if he or she prefers not to be included. As previously mentioned, however, we have found that most participants genuinely enjoy this activity.

We are pleased to have Lynn Miller of Virginia Tech coordinating this project. Mrs. Miller is a former teacher with our school system. If you have any questions or reservations and would like to have more information, please contact Lynn Miller at Virginia Tech (231-5879) or at her home (626-7605).

Thank you for your cooperation in this project.

Respectfully,

Principal

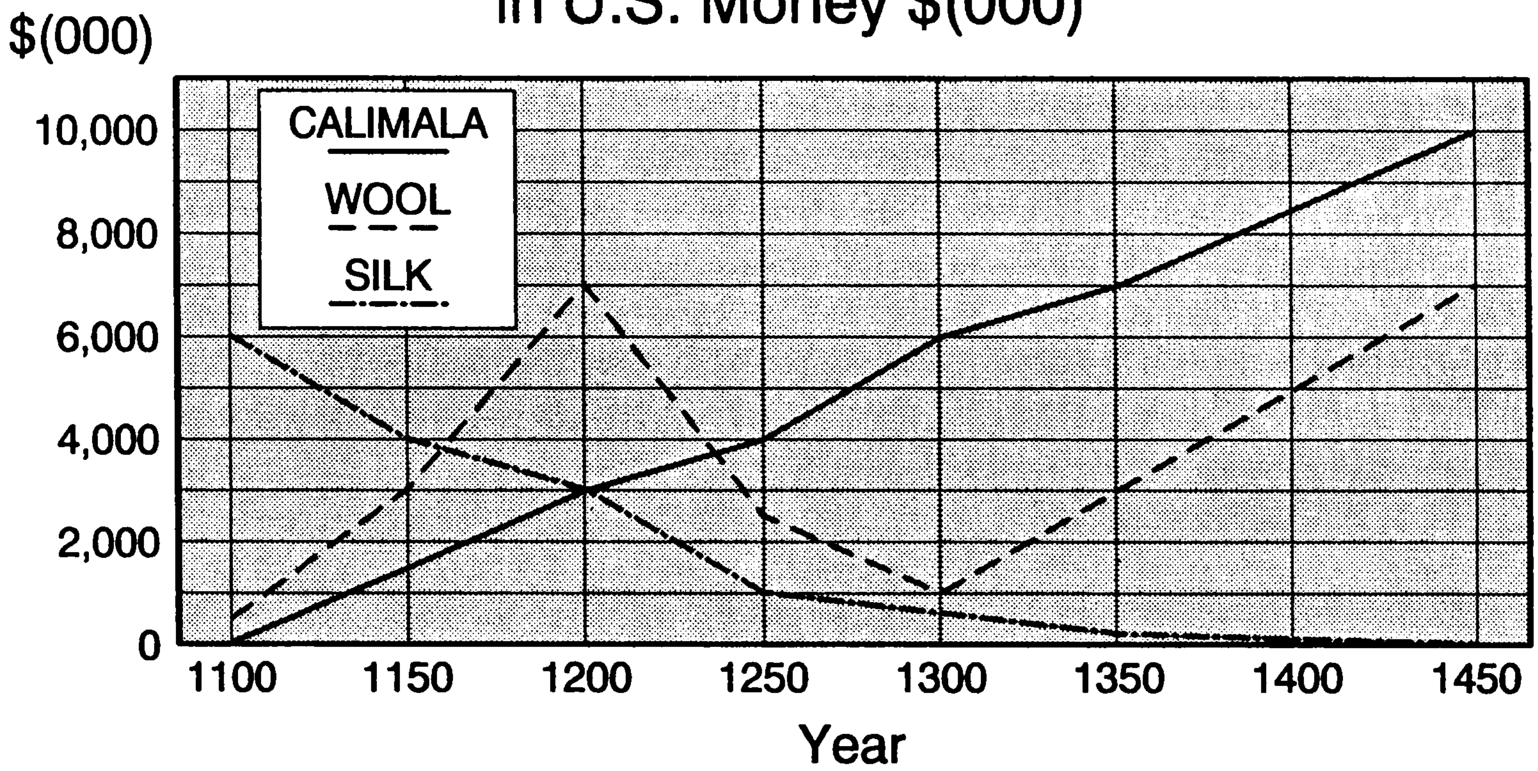
APPENDIX B

Slides: Table, Line-Table, Line, Bar

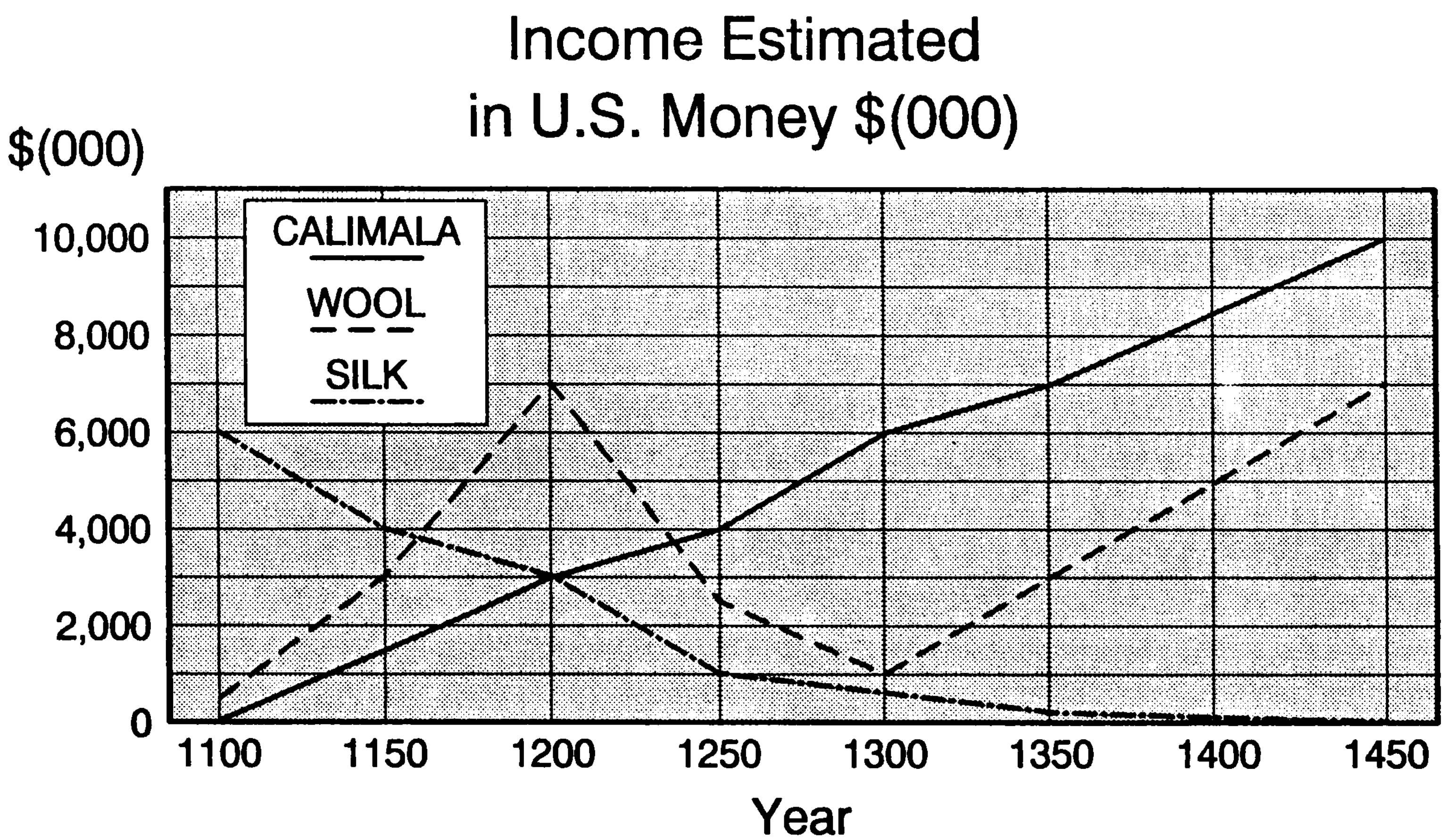
Income Estimated in U.S. Money $(000)

Year	Calimala	Wool	Silk
1100	50	500	6,000
1150	1,500	3,000	4,000
1200	3,000	7,000	3,000
1250	4,000	2,500	1,000
1300	6,000	1,000	600
1350	7,000	3,000	200
1400	8,500	5,000	100
1450	10,000	7,000	20

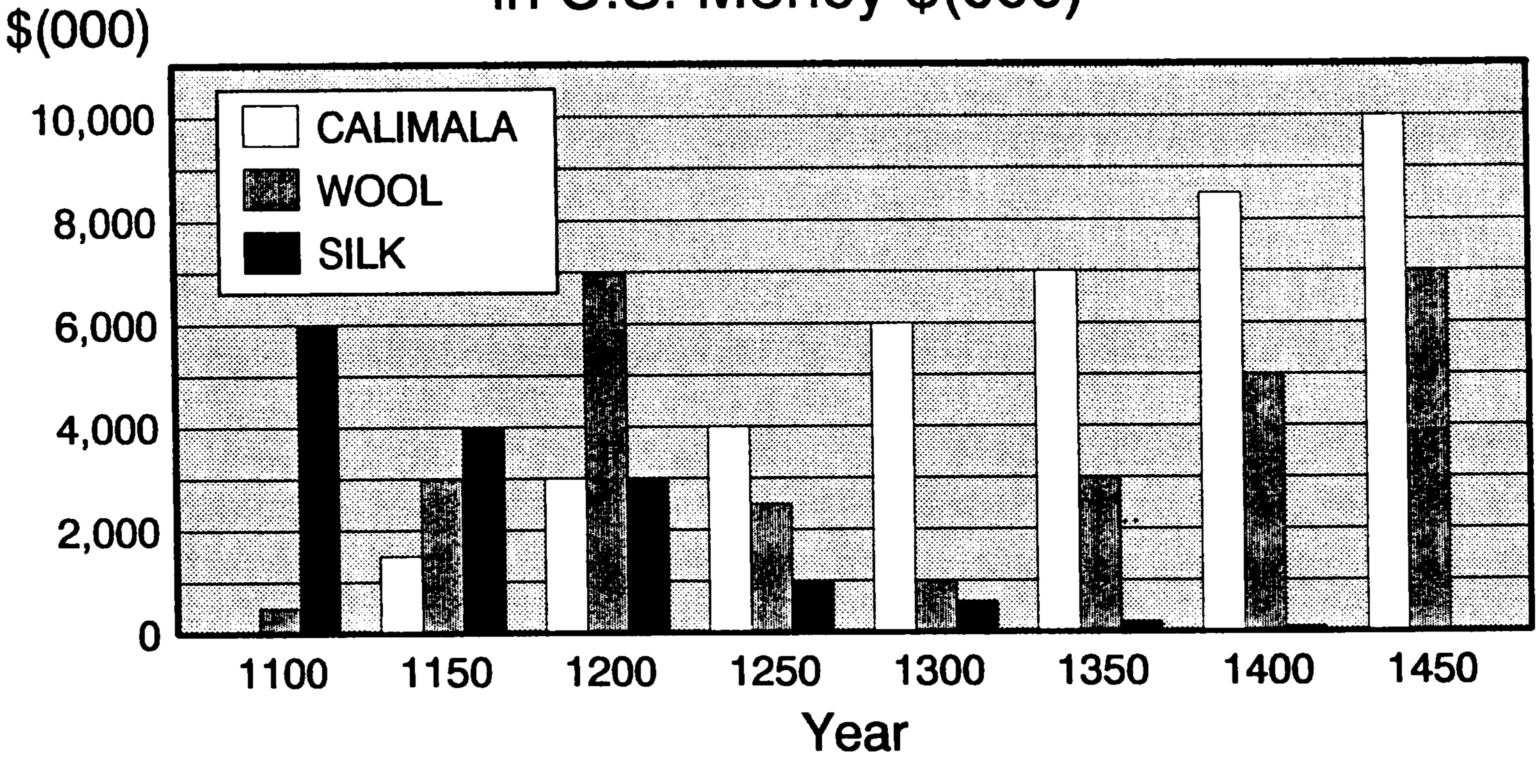
Income Estimated in U.S. Money $(000)



Calimala	50	1,500	3,000	4,000	6,000	7,000	8,500	10,000
Wool	500	3,000	7,000	2,500	1,000	3,000	5,000	7,000
Silk	6,000	4,000	3,000	1,000	600	200	100	20


Income Estimated
in U.S. Money $(000)
$(000)
10,000
8,000
6,000
4,000
2,000
0
CALIMALA
WOOL
SILK
1100
1150
1200
1250
1300
1350
1400
1450
Year

Income Estimated in U.S. Money $(000)



APPENDIX C
Story Narration, Directions, and Test Questions

Part 1

Introduction

In this experiment you will hear a short narration describing the activities of three types of merchants who lived during the Middle Ages. Following the narration, a slide will be projected which shows the income of these merchants over a period of years. While the slide is on the screen, you will be asked a series of questions regarding the content of the slide.

You will have seven seconds to answer each question. At end of the testing period you will receive some additional instructions.

(Pause)

From very early times there was a union of wool-dyers and merchants in Florence who called themselves the Calimala Guild. These Calimala merchants had to send buyers into foreign lands to get wool because the sheep near Florence gave a poor grade of wool. The Calimala merchants had agents in nearly every country in Europe and even in the Orient. They bought raw wool in foreign countries and sold it to the wool manufacturers in Florence.

Cotton cloth was very little known in Europe in those days. Nearly everybody wore wool, and about the only other kind of cloth that was worn was silk. Silk cloth was also made in Florence. So the three big guilds of the city: The Calimala merchants, the wool manufacturers, and the silk merchants supplied a large part of the best clothing in Europe.

(Pause)

You will now see a slide which shows the income of these merchants over a period of years. While the slide is on the screen, you will hear a series of questions regarding the content of the slide. Your responses will be either dollar amounts or names of the merchants. Write your answers on the blank line next to the appropriate question number.

You will have nine seconds to answer each question. The test period will last about ten minutes.

1. What was the income of the Calimala merchants in 1460?
2. Which group of merchants had the highest income in 1350?
3. Which group of merchants had the greatest increase in income in dollars between 1350 and 1450?
4. What was the income of the Silk merchants in 1250?
5. Which group of merchants had the greatest decrease in income in dollars between 1150 and 1350?
6. What was the income of the Wool merchants in 1400?
7. Which group of merchants had the greatest decrease in income in dollars between 1100 and 1300?
8. Which group of merchants had the greatest increase in income in dollars between 1100 and 1200?
9. Which group of merchants had the greatest decrease in income in dollars between 1200 and 1250?
10. What was the difference in income between the Calimala and the Silk merchants in 1200?
11. Rank order (highest to lowest) the income of the three merchants in 1150?
12. What was the income of the Calimala merchants in 1250?
13. What was the income of the Silk merchants in 1150?
14. What was the income of the Wool merchants in 1150?
15. Which group of merchants had the lowest income in 1250?
16. Which group of merchants had the greatest decrease in income in dollars between 1250 and 1300?
17. Which group of merchants had the lowest income in 1150?
18. What was the income of the Wool merchants in 1200?
19. What was the income of the Wool merchants in 1350?
20. Which group of merchants had the greatest increase in income in dollars between 1150 and 1200?
21. Rank order (highest to lowest) the income of the three merchants in 1250?
22. Which group of merchants had the greatest increase in income in dollars between 1150 and 1300?
23. What was the difference in income between the Wool and the Silk merchants in 1150?
21. Which group of merchants had the lowest income in 1100 ?
25. What was the income of the Calimala merchants in 1300?
26. Which group of merchants had the highest income in 1150?

27. Which group of merchants had the greatest decrease in income in dollars between 1150 and 1400?
28. What was the income of the Calimala merchants in 1350?
29. What was the income of the Calimala merchants in 1200?
30. Which group of merchants had the highest income in 1200?
31. Which group of merchants had the highest income in 1250?
32. Which group of merchants had the greatest decrease in income in dollars between 1200 and 1350?
33. Which group of merchants had the lowest income in 1300?
34. Which group of merchants had the greatest decrease in income in dollars between 1250 and 1350?
35. What was the income of the Silk merchants in 1100?
36. What was the difference in income between the Calimala and the Silk merchants in 1250?
37. What was the difference in income between the Calimala and the Wool merchants in 1450?
38. Which group of merchants had the greatest increase in income in dollars between 1100 and 1250?
39. Which group of merchants had the greatest increase in income in dollars between 1200 and 1350?
40. What was the income of the Silk merchants in 1200?
41. What was the income of the Wool merchants in 1450?
42. Which group of merchants had the greatest increase in income in dollars between 1250 and 1450?

PART 11

You will now have one minute to form a mental picture of the slide on the screen. After one minute the projector will be turned off and and you will be asked five questions regarding the content of the slide. You will have seven seconds to answer each question.

(Pause}

1. Did the Calimala merchants income ever exceed that of the Wool merchants during the time period described in this experiment?
2. Which group of merchants had the highest income at the beginning of the time period described in this experiment?
3. Which group of merchants had the lowest income at the end of the time period described in this experiment?
4. Which group of merchants had the highest income at the end of the time period described in this experiment?
5. Which group of merchants showed a sharp increase in income, then showed a sharp decrease, and finally recovered in the latter years of the time period described in this experiment?
6. Did the silk merchants income ever fall below that of the Calimala merchants during the time period described in this experiment?
7. Which group of merchants had the highest income at any time during the time period described in this experiment?
8. Which group of merchants had the lowest income at any time during the time period described in this experiment?
9. Which group of merchants made a steady decrease or loss of income over the time period described in this experiment?
10. Which group of merchants made a steady decrease or loss of income over the time period described in this experiment?
11. What year did the Silk merchants and the Calimala merchants have the same income?
12. Was it the beginning, middle, or end of the time period that all three merchants were further apart from each other in total amount of income?
13. Which group of merchants made the most income during the entire time period described in this experiment?
14. Which group of merchants made the least amount of money during the time period described in this experiment?

APPENDIX D

Student Answer Sheet

Visual Materials Project

Part 1

Group: B L L-T T

AGE________BIRTHDATE_______________ Sex: M F

1. ________________
2. ________________
3. ________________
4. ________________
5. ________________
6. ________________
7. ________________
8. ________________
9. ________________
10. ________________
11. ________________
12. ________________
13. ________________
14. ________________
15. ________________
16. ________________
17. ________________
18. ________________
19. ________________
20. ________________
21. ________________
22. ________________
23. ________________
24. ________________
25. ________________
26. ________________
27. ________________
28. ________________
29. ________________
30. ________________
31. ________________
32. ________________
33. ________________
34. ________________
35. ________________
36. ________________
37. ________________
38. ________________
39. ________________
40. ________________
41. ________________
42. ________________

##

Part 2

1. ________________
2. ________________
3. ________________
4. ________________
5. ________________
6. ________________
7. ________________
8. ________________
9. ________________
10. ________________
11. ________________
12. ________________
13. ________________
14. ________________

APPENDIX E

Analysis of Variance of Graph, Age, and Gender

across the Four Question Types

Appendix E

Analysis of Variance of Graph, Age, and Gender by the Four Question Types

Source	df	MS	F
Between-Subjects			
Graph	3	63.60	5.54**
Gender	1	3.34	.29
Age	1	870.85	75.80**
Graph by Gender	3	3.76	.33
Graph by Age	3	1.08	.09
Gender by Age	1	21.46	1.87
Graph by Gender by Age	3	1.83	.16
Error	242	11.49	
Within-Subjects			
Question Types	3	268.86	83.46**
Graph by Question Types	9	25.91	8.04**
Gender by Question Types	3	3.01	.93
Age by Question Types	3	29.68	9.21**
Graph by Gender by Question Types	9	5.98	1.86*
Graph by Age by Question Types	9	14.94	4.64**
Gender by Age by Question Types	3	3.96	1.23
Graph by Gender by Age by Question Types		9	4.84
1.50			
Error	726	3.22	

* p<.055

** p<.01

APPENDIX F

Simple Interaction Effects of Graph by Question Types

Appendix F

Simple Interaction Effects of Graph by Question Types

Source	df	MS	F
Graph at Amount	3	60.97	11.53**
Graph at Static	3	49.68	9.39**
Graph at Dynamic	3	25.05	4.74**
Graph at Recall	3	21.57	4.08**
Error	664	5.29	

** $p < .01$

APPENDIX G

Simple Interaction Effects of Age by Question Types

Appendix G

Simple Interaction Effects of Age by Question Types

Source	df	MS	F
Age at Amount	1	147.63	27.91**
Age at Static	1	322.04	60.88**
Age at Dynamic	1	498.27	94.19**
Age at Recall	1	107.35	20.29**
Error	664	5.29	

** $p < .01$

APPENDIX H

Simple Interaction Effects of Graph by Age by Question Types

Appendix H

Simple Interaction Effects of Graph by Age by Question Types

Source	df	MS	F
High-School Students			
Graph at Amount	3	22.87	4.32**
Graph at Static	3	17.94	3.39*
Graph at Dynamic	3	2.96	0.56
Graph at Recall	3	16.40	3.10*
Elementary Students			
Graph at Amount	3	36.53	6.91**
Graph at Static	3	28.68	5.42**
Graph at Dynamic	3	39.76	7.52**
Graph at Recall	3	8.81	1.67
Error	664	5.29	

* $p < .05$

** $p < .01$

APPENDIX I

Simple Interaction Effects of Graph by Gender by Question Types

Appendix I

Simple Interaction Effects of Graph by Gender by Question Types

Source	df	MS	F
Males			
Graph at Amount	3	23.12	4.37**
Graph at Static	3	23.87	4.51**
Graph at Dynamic	3	20.70	3.91**
Graph at Recall	3	12.23	2.31
Females			
Graph at Amount	3	40.75	7.70**
Graph at Static	3	5.61	5.61**
Graph at Dynamic	3	6.48	1.22
Graph at Recall	3	15.63	2.95*
Error	664	5.29	

* $p < .05$

** $p < .01$

The __4__ page vita has been removed from the scanned document

The vita has been removed from the scanned document

The vita has been removed from the scanned document

The vita has been removed from the scanned document