

Research on Reading and Interpreting Computer Generated Graphs Using Eye-Tracking Technology

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One of the most frequent and valuable uses of computers in the mathematics classroom is for computer generated graphs of mathematical functions and relationships. New advances in calculator technology include interactive graphics capability on hand-held machines. Computers and graphing calculators can generate a wide variety of graphs of functions and relationships. But, more importantly, these machines provide speed and flexibility to produce multiple graphs and to manipulate these graphs in various ways. A student can graph more functions in a three-hour homework session using this technology than would normally be done in an entire year of mathematics instruction. Students are free to manipulate factors such as scale, rotation, translation, and viewing area in the plane. With the increasing availability of micro computers and inexpensive graphing calculators, this use of technology in the mathematics classroom will increase in the future. This paper provides research evidence that suggests increased use of technology can enhance students graph reading ability in the same way that practice in reading text improves text reading ability.

Graphs are an important teaching and learning tool which allow students to visualize the relationship between variables in a mathematical expression. Recent assessments of mathematical skills (National Assessment of Educational Progress; Carpenter, 1975, 1980, 1983; Second International Mathematics Study; Travers, 1985) have shown students were able to read simple graphs but could not perform related skills such as interpreting, generalizing, integrating, or extending the information in a graph. There is little empirical evidence about how the human visual system decodes the symbol system we call a graph. With the research evidence concerning students' skill levels and the increasing use of computer and calculator generated graphs in learning and teaching mathematics, it seems appropriate to ask basic questions about how people read and interpret mathematical graphs. This information will be helpful in designing new curriculum materials and teaching methods which will make better use of the technology in the classroom.

This research study used eye-tracking technology to investigate how subjects read polynomial graphs generated by a computer. Eye-tracking technology allowed precise measurement of the location and duration of the subjects' gaze while viewing the graph on the computer screen. The eye-tracking computer used an inferred sensitive television camera to measure the angular rotation of the eye. This angular rotation was mapped to a location in the viewing plane. Data on the

location of the viewing position was updated 60 times per second. This was three times as fast as the eye could establish a focal point and transmit visual information to the brain. The duration of a single visual fixation was then the sum of the $1/60$ second readings when the eye was focused on a given point.

Typical fixation durations while reading were from 150 to 400 milliseconds with the average fixation duration of about 250 milliseconds.

The study attempted to define the differences and similarities between novices and experts on the variables of fixation duration and total time spent viewing polynomial graphs generated on a computer screen. For the analysis of viewing patterns, the graphs were blocked in a grid pattern (see figure 1) and grid squares were categorized by the graphical features contained within them. Important areas of the graphs were grid squares which contained features critical to interpretation of the graphs such as scale, intercepts, and maximum, and minimum points. Fixation duration was defined as the average length of a fixation when viewing areas of the graph.

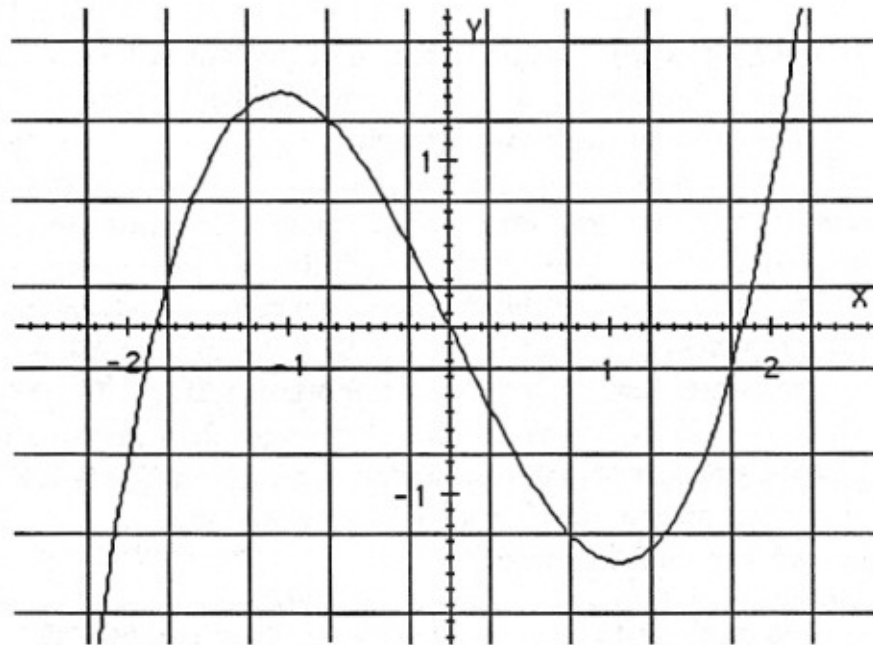


Figure #1 Graph showing blocking used to define important and unimportant area of the graph.

Each subject was allowed to view a graph for up to one minute. Subjects could self-select to stop viewing at any time up to the one minute. Since each subject's total viewing time could vary, the total viewing time variable was stated as a percent of total time spent. For the important areas of the graph, the percent

of the total time spent in each important area was compared. For example, a subject may have viewed a certain graph for 45 seconds and of that total time spent 5.4 seconds, or 12% of the total time, looking at the grid area containing the y-intercept of the graph. Another subject may have spent 7.2 seconds of a total viewing time of 60 seconds looking at the same grid area. This would also represent of 12% viewing time in that grid area.

Twenty-five expert and twenty-five novice subjects participated in the study. Novice subjects were students enrolled in remedial mathematics courses at a large Midwestern university. Expert subjects were graduate students and professors in mathematics and mathematics education. Each subject viewed five different polynomial graphs and completed a memory task immediately after viewing each graph.

Data was analyzed using MANOVA, Pearson Correlation, and Spearman Rank Correlations procedures. Multivariate analysis of data from important blocks of the graphs indicated that the fixation durations were significantly different ($p < .05$) between experts and novices for 4 of 5 graphs. The percent of total time variable did not differ significantly for the two groups of subjects. For unimportant blocks of the graphs, there was no significant difference between experts and novices for either fixation duration or percent of total viewing time. Correlation analysis indicated that subjects were consistent between variables and within themselves across all the viewed graphs.

Results of the study indicated that novices and experts were able to locate the important areas of the graph and spent approximately the same amount of time viewing those areas. However, experts had significantly longer average fixations when viewing important areas of the graphs. This contradicted the notion that familiarity with graphs would cause experts to be faster in processing graphical information. When an expert fixated on an important feature of a graph, the average length of each fixation was significantly longer than that of a novice. Experts were processing the visual information in a different way than novices. When experts viewed unimportant areas of the graph, they did not differ from novices on the two variables assessed.

Results of the study imply that a graph is an effective symbol system for drawing a viewer's gaze to the important information. Once viewing the important information, experts spent more time during each fixation before moving their eyes. Longer fixation durations imply more complete cognitive processing. Just and Carpenter (1980) contend that fixation duration is a direct measure of cognitive processing of the information being viewed at the present time. Experts were able to control their viewing strategy in response to the type of information being viewed at the moment. Novices, however, were not able to shift to the longer fixations when viewing important information even though they spent as much total time as the experts viewing the important information. Shebilske and Fisher (1981) found fixation durations to be longer in areas of text

passages containing more important ideas than in other less important areas. This observation also seems to be true for expert graph readers, but not novices.

What factor taught experts to shift their viewing strategy for the important information? More experience using graphs by experts seems to be one probable explanation for the differences between the two groups. Like reading text, the more experience a reader has, the more sophisticated he/she becomes in reading techniques. This seems to be true for reading graphs or text. While both groups were drawn to the important information, experience probably taught experts that longer fixations are needed to process more completely the important information. If experience reading and interpreting graphs is an important factor in improving graph reading skills, then increased use of technology to generate graphs would be appropriate in mathematics classrooms. Producing accurate graphs by plotting points is an inefficient way to give students experience with graphs. Using graphing technology in classroom for all types of activities, including lectures, demonstrations, work sessions, homework, explorations, concept development, problem solving, and testing, will provide students with significantly more experiences using graphs.

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