DISTRIBUTED COGNITION, COMPUTERS AND THE INTERPRETATION OF GRAPHS

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Abstract

One aspect of recent research on students' understanding of graphs in computer and in pencil and paper media is reported on. Over 200 Year 10 students in two comprehensive schools in Leeds participated in a teaching experiment, 100+ with and 100+ without the use of computers. Pre/post-tests and interviews provide data for a comparison of learning with the two media. The wider study examines students' construction and interpretation of context graphs (related to situations) and context free graphs (x-y graphs). This paper concentrates on students' interpretation of context free graphs.

Introduction

I report on research examining students' understanding of Cartesian graphs in computer and paper and pencil media. My focus in this paper is an examination of students' interpretation of graphs in the light of theories of distributed cognition. Dorfler (1993) suggests that we view cognitive processes as a system made up of the individual, the whole context and the multiple relationships between them. Cognition is viewed as being distributed over the tools which aid the thinking process and mathematical problem solving is no longer viewed as a purely mental function. Perkins (1993) extends this idea to social resources and claims that these resources are not mere sources of input and receivers of output but are vehicles of thought. Other workers in the field make similar claims without mentioning the term distributed cognition, e.g. Hoyles et al. (1991) emphasizes the role of social interaction with the environment and claims that this provides the scaffolding for the solution of the task.

Considering computers and graphing, Ainley (1995) and Pratt (1994) claim that computer use allows students to focus on the context and the purpose for which the graph is constructed. McKiernan (1993) claims that students taught by a computer aided approach achieved better results than those by the traditional method. Ruthven (1990), however, suggests that technology does not by itself enhance the ability of students to interpret graphs.

Although the above studies and others related to student learning of graphs state difficulties or misconceptions or claims of success in learning graphing skills, these findings are not categorized entirely on graphical information, that is the covariance of the two variables. They are discussed as separate entities such as slope, height confusion, pictorial perception, etc. These reports do not state which or what type of graphical information draws students to face these difficulties nor which specific aspects of graph information are learnt successfully by the students as a result of a particular strategy or experience. To address this I turn to levels of graph information.

Levels of graph information

A personal need to specify what aspects of graphing posed problems led me to categorize graph information into what I call 'levels of graph information'. The idea was initiated by Clement's (1989) static and dynamic knowledge representations. His static representation is what I call Levell, pointwise information: This level refers to one set of lengths from the origin resulting in a point. Trend of change throughout a graph cannot be expressed by information in this level. His dynamic representation, is what I call Level 2, slope-wise information: This level is relevant when changes in length along one axis are compared to a simultaneous change along the second axis concerning the covariance of the variables.

So, static representations provide information about a point and dynamic representations provide information of the covariance of the variables, but how is this covariance taking place and how do students use it to construct and/or interpret the shapes of graphs? To address these questions I added a third level, which may be regarded as the derivative, though I will not use this term again in this paper. Level 3 information is a comparison of slope-wise information. Information from this level enables one to state if the change is changing more quickly, more slowly or constantly.

Methodology

A general graph test was used to divide the sample in each school into two groups of matched pairs. One group, referred to as the computer group, worked through sets of computer-based learning modules using spreadsheets. The other group, the paper group, worked through equivalent learning modules in the traditional paper and pencil medium. Both groups had completed a pre-test a week before the treatment with the learning modules and a post-test a week after the learning modules. 20 students, 10 matched pairs, were interviewed after the post-test.

The learning modules

Students constructed graphs from tables of data. The tables of data for the computer group were on the screen in a spreadsheet format. The tables of data for the paper group were in booklets. The computer group generated graphs on the computer, on scaled numbered grids. The paper group constructed the graph on scaled numbered grids. In the next stage the graphs were interpreted with the help of notes provided. Finally the students referred to the answers for the detailed explanation. The learning session for this part of the work lasted about one hour.

Test and interview items

The test items relevant to this report both presented students with two non linear intersecting graphs, one with positive and one with negative gradient. The graphs for question 1 (Q1) were drawn on a numbered grid while those for question 2 (Q2) were drawn on unnumbered axes. Q1 consisted of 13 doze form objective items while Q2 consisted of 7 doze form objective items and 8 multiple choice items. A score of one was given for a correct response and zero for no or incorrect response. The interview item relevant to this report consisted of a series of questions on a given piece-wise linear graph with sections with positive, zero and negative gradients. As well as collecting qualitative data interview responses were given an overall score.

Results and Data Analysis.

The hypothesis for this part of my research was that there would be no difference in performance for the two groups of students. The table below provides the mean improvement score.

Table 1: Graphs Interpretation Levels (Post - test)

df= 100, n = 101, MIS = Mean improvement score, *clp* denotes computer or paper group

Level	Paper: MIS	Computer: MIS	t-value	p-value	c or p /Sig
1	0.1485	0.2153	1.12	0.267	c
2	0.2706	0.3503	1.29	0.199	c
3	0.3267	0.4616	2.10	0.038	c/s
Overall	0.7459	1.0273	2.07	0.041	c/s

The overall and level 3 difference in mean improvement score between the two groups is statistically significant with the computer group improving more than the paper group.

Discussion.

(i) Do these statistics indicate that computer use positively aids students' interpretation of graphs? According to the distributed cognition paradigm the computer takes over a large part of the cognitive process, that is the scaling, deciding which variable goes on which axis and the final process of constructing the graph. To what extent can it be said that this is happening here and what other factors might impinge on student performance? Computer group students had to follow the instructions to command the computer to convert the table of data into a graph which was displayed on the screen. It appeared that their attention was focused on interpretation. In the paper medium students constructed graphs by translating the table of data into points and then completing the

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construction of the graph. This process was arguably the focus of attention, making the construction an end in itself These two related issues, 'focus of attention' and 'end in itself, are, I believe, relevant to issues of distributed cognition in this study.

In the learning module, 5 out of the 10 students who were interviewed from the paper group compared to 2 out of 10 from the computer group had incomplete or non-attempted or unsatisfactory responses for the interpretation section. Unsatisfactory responses here refers to responses which do not focus on interpretation. Interviews with these five students gave strong indicators that they did not focus on the interpretation and that the construction was an end in itself Noticeably, the two students in the computer group who did not complete the interpretation tasks had hardware problems which posed difficulties during construction.

Computer generated graphs which can be dragged around enable students to compare different graph structures and to realize the relationship between them. Such learning, where students relate successive experiences in a short time period, has been called discrimination learning (Estes, 1976). If the relationships are not realized during learning then this may lead to interference during recall. This was evident in students from the computer group. A girl in this group, when asked to explain her correct response to the question, "With constant increases in x, y increases by smaller and smaller amounts" explains it as "It wasn't going as fast as it was that curve there. Oh! It wasn't decreasing but it was decreasing but it wasn't as great as there, the curve isn't as steep as it is there".

She had differentiated between the two sections' steepness and arrived at her answer. However, her matched pair, a boy in the paper group, explained his correct response as "Because between points here in the y-axis, it only moves up by slight amount. It doesn't move up as greatly as between these points" He had compared an increase in y for different increases in x. He had tried to differentiate between the graph structures but focused on level 2 rather than level 3 information.

The construction of graphs in the paper medium itself demands attention for a considerable length of time. To then proceed to interpretation required students to switch attention which, according to Norman (1976), may blur perception and cause confusion. Evidence of confusion was more prevalent among students in the paper group than in the computer group and is discussed in the next section. One may argue that providing a graph to the students allows focus of attention on one aspect but this eliminates construction. The computer does not eliminate construction and yet allows a focus on interpretation. This, I believe, accounts for the computer group improving more than the paper group. The interview scores of 80% by the computer group and 63% by the paper group provide further support that the computer medium enhances students' interpretation skills more than the paper medium.

The benefits of computer use in the learning modules center on students being able to use comparison of slope (level 3) information in the interpretation of graphs.

Based on the general graph test, more than 90% of the students demonstrated a knowledge of level 1 information. Interview data also shows no difference between groups for level 1 information.

Level 2, slope-wise information may be interpreted based on memorized cues (Clement, 1989), that is a positive gradient is an increase in y, negative gradient a decrease and a line parallel to the x-axis as no change. Interview responses such as "that line, because it's a flat line" provide evidence for this. There is however evidence in the interview responses which shows that students in the paper group are confused or unable to explain their responses to level 2 items. This did not occur among students from the computer group and, I argue, accounts for the computer group improving more than the paper group. Further support comes from the interviews where the computer group scored 83% while the paper group scored 60% for level 2 items.

The level 3 graph information was least known to students, as was shown from their responses in the pre-test. The computer appeared to allow students more time to focus their attention on interpretation while the switching of attention from construction to interpretation may blur perception and cause confusion. This is supported by the interview responses from the paper group. A girl from the paper group explains her response to a level 3 question as follows, demonstrating confusion: "Because it changes by decreasing and then increasing a little. Just before the curve. From here to here is increasing a little. Well about the same amount as the curve, not all not increasing but about the same amount. No it is here, because that increases on x be half from y changes but increases but x is more". Several other students from the paper group also demonstrated confusion. The students in the computer group however demonstrated a systematic manner in arriving at their answers. The interview score for level 3 information was 53% by the computer group and 30% by the paper group, providing further support that the computer medium enhances interpretation skills more than the paper medium.

Conclusion

There is a difference in improvement between the two groups in interpreting graphs. The computer group improved more than the paper group. This study provides evidence that the element which results in the difference between the two mediums for learning graph interpretation is due to the difference in the distribution of cognition over the tools and the individual. In the computer medium a large portion of the cognitive process for construction is taken over by the tool compared to the paper medium. This allowed more time for students to focus attention on interpretation while the paper medium led students to see construction was an end in itself Interpretation of the various graph structures could further be refined through discrimination learning in the computer medium due to the efficiency of graph production by the computer and the mobility of the graph on the screen. This compared to the less efficient graph production combined with graphs on fixed pages in the learning module in the paper medium was not conducive for discrimination learning. The combination of these factors result in the computer medium enhancing interpretation skills more than the paper medium in students.

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