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# Can Juniors Read Graphs? A Review and Analysis of Some Computer-Based Activities

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ABSTRACT This article reviews three published studies that appear to show that children as young as seven or eight can understand line graphs and scatter graphs to a greater extent than was previously supposed. These results are contrasted with frequent reports of poor graphical interpretation by students in secondary school. Given time and support, junior age children can carry out a wide range of interpretation tasks with graphs. In predicting their performance, the context of the graph seems to be more important than its syntax. An analogy is drawn between the acquisition of graphing skills and learning to play board games. It is argued that it is more important that the curriculum provides a rich and varied diet of graphical experiences, than a detailed teaching of graphical syntax. Information handling activities with computers are seen as an important way to achieve this.

## Introduction

The use of information technology sometimes changes our preconceptions about the best age for teaching ideas in school. Recent evidence has suggested that children as young as seven or eight can understand line graphs and scatter graphs to a greater extent than was previously supposed. This paper reviews and analyses this evidence, and questions whether we should reconsider the way graphical information is taught in junior schools.

Set in an historical context, graphic information is a recent phenomenon. Although maps have been used for more than 5,000 years, most other forms of graphic information came into use in the last 200 years – line graphs are a surprisingly modern discovery (Tufte, 1983). Computer usage has both increased access to information graphics and led to the development of new representations (e.g. those developed for exploratory data analysis).



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Much of the formal research in this area has focused on the secondary age range. Janvier (1978) studied the graph interpretation skills of 12 - 15 year olds and identified a number of frequently occurring misconceptions. As part of the CSMS research, Kerslake (1981) reported data from more than 1,000 students aged between 13 and 15 years who were given a range of graph reading tasks.

There has been an increasing awareness of the distinction between low level skills (e.g. reading off a value, plotting a point) and higher level skills (e.g. telling a story to explain the data). Innovative materials aimed at developing higher level skills (e.g. Swan, 1986) are recently beginning to be accepted in the classroom.

Bell et al (1987) applied diagnostic teaching methods to graphical interpretation. They identified four main areas of misconception in the understanding of graphs by 14 year olds:

- Interpreting a graph as if it were a picture (or as if it were some other kind of graphic display).
- Misinterpreting the relationship between two variables.
- Difficulties in understanding the shape of a graph (e.g. linear vs. curved).
- Difficulty in the interpretation of gradients and intervals.

With so much research on the inadequacies of graphical interpretation by secondary-age students, it might be assumed that graphs have no place in the junior school. Although the English National Curriculum now requires graph work at Key Stage 2, graphs have not been extensively taught at primary level and work with graphical information has largely been limited to bar charts and maps. However, as the studies reviewed in the next section show, juniors can do more with graphs than might be expected.

## Review of Published Studies

It is helpful to review the evidence that comes from a number of published studies about the graph interpretation skills of junior age children (7-11 years).

### *First Study: Travel Graphs*

Avons et al (1983) studied 9-11 year old children who were exposed to computer animated distance-time graphs linked to a picture of a moving car. Then, away from the computer, their understanding of similar graphs was assessed with a test. The procedure lasted 30-40 minutes.

The aim of the study was to compare different treatments at the computer that varied in the type of interaction and the screen presentation. However, the differences between these treatment groups were small and the interest here is in the level of graph interpretation revealed in all the groups studied.

In the test, children were shown a graph similar to that in the computer display and composed of several line segments representing one of five speeds (fast forward, slow forward, stationary, slow backward, fast backward). They were asked to say what sequence of movements by the car was depicted. The mean score was 73% showing a fair understanding of the relationship between gradient and speed. There was a similar level of performance (75%) in a production test, where children were told a sequence of movements made by the car and were asked to sketch these as a graph.

There was poorer performance (40%) in a conceptual test which extended the ideas in the original activity. When asked about duration rather than speed, only one child answered correctly. Although they had connected gradient with speed, there was a failure to resolve the time and position measures from a graphical segment. There was some conflicting evidence from the test on how well they could generalise the speed/gradient relationship. Only one child correctly interpreted a curved line. However, about half could sketch a graphical segment steeper than that corresponding to the fast forward speed. This generalisation could be taken as evidence of conceptual understanding.

The children had had no previous formal instruction with journey graphs and from this brief computer-based experience they had learned the association of the five speeds with five gradients, and showed a limited ability to generalise this. They had little difficulty with the representation of a journey as a sequence of graphical segments read from left to right and they could sketch a graph of this type.

However it was quite apparent that they did not connect the gradient with its horizontal and vertical components on the axes. The relationship between speed and gradient was learnt directly. Understanding was limited to straight line segments and could not be generalised to curves.

### *Second Study: Classroom Data Logging*

Corcoran (1991) and Morgan (1992, 1993) have both reported lessons where children aged 7 and 8 years have shown a surprising proficiency in interpreting a multi-variable line graph. Data logging boxes were demonstrated to the children and set up to collect data about the classroom environment over a 24 hour period in their classroom. This produced a time graph showing sound level, light level, temperature, and movement over a pressure mat.

Part of the graph showed events when the children were present in the classroom and could relate features on the graph to what they could remember. But the graph also continued throughout the night. Evidence of understanding comes largely from discussions between the teachers and groups of pupils.

Most could read the graph as a 'time line' along which events were marked. They could point out their arrival in the morning by an increase in noise and lots of activity on the pressure mat. It was equally easy to identify break times and their departure. They could often relate events on different lines on the graph, for example a light being switched on at the same time as a noise.

Quantitative understanding was more limited but most could grasp that as the sound line grew higher, the noise level increased. They could distinguish quiet talk from more noisy events like singing. Some could distinguish a sudden change of light level (an electric light switched on) from a gradual change (the sun rising). Not everything on the graph could be interpreted satisfactorily. One classroom had a heater with a thermostat which generated a gentle wave pattern in the temperature graph. Children noticed it and described it as 'like waves in the sea' but could not explain it either in terms of what was happening to the temperature, nor in terms of a likely cause.

One class were particularly intrigued when the paper coming from the printer showed evidence of human activity in the classroom at 6pm. The mat had been trodden on, there was a noise but the room was still in darkness. When exactly the same happened at 9pm some children were convinced it was 'a robber'.

> ...We were here at nine o'clock?
> This is nine o'clock at night.
> How do we know they didn't switch the light on?
> The line is straight.
> How could they see?
> They had a torch.

A little detective work led them to discover the true source of the events at 6pm and 9pm.

In one lesson described by Morgan, the initial experience of seeing graphs from the data logging box, led into creative work away from the computer involving sketching and labelling graphs. One student drew a noise graph for a football match showing a louder crowd response for a home goal than for an away goal.

These 7 and 8 year olds demonstrated a considerable degree of understanding of a multi-variable line graph, as a portrayal of events in time.

### *Third Study: Scientific Investigation*

As part of an investigation of laptop computers in primary schools, Pratt (1994, 1995) worked with groups of children aged 8 and 9 years using spreadsheet software to record and interpret data they had collected. In one study three boys made paper spinners and studied how the time of flight was affected by changing the spinners' wing length. After each trial they entered data directly into a spreadsheet. The teacher was able to observe stages in their understanding by discussing with them the scatter graph plots produced. Initially they were able to relate four crosses on the scatter graph to their four observations. With more data they could superimpose a straight line, but not interpret it. But at a third interview, one boy offered the interpretation 'The longer wings stay longer in the air' and another boy drew attention to an outlier. Later, an incorrectly entered data point was not noticed until a new scatter graph was plotted. In a final interview, with 13 crosses on the scatter graph, the group realised 'It's an up and then down pattern!'. They superimposed two straight lines in an inverted V shape and were able to read off the maximum to predict the best wing length to use when making spinners.

Pratt gives similar accounts of scatter graph interpretation in other contexts. In one of these, children worked on how the distance travelled by a toy car was affected by the height of the ramp down which it rolled. In another, a group of girls worked on how the weight of a pendulum bob affects its time of swing. They also used the scatter graph to identify and correct spurious data, and eventually, to arrive at the conclusion that the weight of the bob had no effect on the time.

Extended activities with appropriate support from the teacher can demonstrate quite advanced graphical interpretation skills. The children understood that points on the scatter graph represented pairs of readings and that a straight line can describe a collection of scatter graph points even though it does not pass through them exactly. They could interpret a trend on a scatter graph. They could identify outliers and try to explain them.

### *Other Studies*

There are a number of other reports where computer-based activities have led to primary age children working effectively with graphs. Motion sensors that draw distance-time graphs in real time provide a very concrete experience of graphs. Mercer (1994) describes 9 and 10 year olds working in this way. Another rich area of experience are activities that relate graphs to stories. For example, Stewart (1983) describes 10 year olds devising stories to accompany software that plots a graph of the water level in an imaginary bath.

## Discussion

Some caution is needed because the results from the second and third studies have been collected in a way that makes it difficult to estimate what proportion of the class were capable of understanding each aspect. Nevertheless the range and depth of understanding demonstrated by some junior students is impressive. They are capable of a wide range of operations with graphs that include some understanding of gradients, the linking together of information on two separate lines on a graph, and the use of scatter graphs to see a trend.

The work demonstrates the use of graphs at higher cognitive levels for interpretation, story telling, and hypothesis generating. In Phillips's (1986) analysis of information graphics in terms of the removal of cognitive loads, these junior children are seeing complex relationships between data which could not be seen if the information was only available to them in symbolic form.

### *Context or Syntax?*

It is pertinent to ask how much understanding depends on the content of the information and how much on the conventions of graphical presentation. In other words, how much is context and how much is syntax? The importance of the context of a graph is demonstrated in a study by Preece and Janvier (1993) where 14 and 15 year olds interpreted two graphs with the same syntax but with different contexts. In the three studies reviewed here, it is certainly not easy to generalise about the syntactical aspects of the graph that juniors can handle, and it is probable that the content of the information is of greater importance.

For example in the second study, children could not interpret a wave-like temperature graph caused by a thermostat. A syntactic explanation might be that sinusoidal graphs are just too difficult for this age group. But Mercer (1994) reports that juniors could interpret very similar looking graphs made with a motion sensor. A more likely explanation is the context: thermostats are just outside most juniors' experience.

### *A Discrepancy?*

A large number of studies have drawn attention to the inadequate graph interpretation skills of secondary and older students (e.g., Vernon, 1946; Kerslake, 1981; Padilla et al, 1986; Swatton & Taylor, 1994; McFarlane, 1994). Is there a discrepancy between these studies and the primary studies that show evidence of a wide range of graph interpretation skills?

In the 1970s a similar situation was noted with children's map reading skills. Many were delighted by the discovery that very young children could do more than they expected with maps. For example, Stea & Blaut (1973) reported that children of kindergarten age can interpret large scale maps of their own locality, and trace their route from home to school. This was contrasted with what was seen as the poor performance of secondary students in interpreting topographic maps.

In both cases the development of graphical information appears to tell a story of early promise and later confusion. But the results need careful scrutiny and there is a danger of not comparing like with like.

*Active Graphing*

The interactive nature of all three junior studies could contribute to the level of graphical understanding. In the third study, Pratt (1994) suggests 'that by using graphing in an interactive way as part of an experiment (a process we now term 'active graphing'), the graphing was given a sense of purpose, which was helping some children to gain access to a more sophisticated understanding of graphs.'

Unfortunately this cannot be a complete explanation. Although the first two studies are arguably interactive, they do not meet Pratt's (1995) definition of 'active graphing' as there is no feedback loop linking the viewing of the graph to a decision about what data to collect.

A broader definition of interactivity could encompass all three studies, but there is still a difficulty. Avons et al (1983) systematically varied aspects of the interactivity with their computer display, but found very little difference in performance. Morgan (1994) has compared groups of children who were involved in collecting data on a graph, with others who were not involved. Graphical understanding assessed by interview showed surprisingly little difference between the two groups.

In the three reviewed studies, the length of the activity and the engagement of the children are probably significant factors, but it is not easy to attribute their performance to particular aspects of interactivity.

## Board Game Analogy

One way to think about children's learning of information graphics is to draw an analogy with learning in another domain. As children grow up, they meet a wide range of board games - snakes and ladders, monopoly, chess, and so on. To play a game they have to learn a set of rules and then gradually develop strategies as they play. Even with some popular children's games, the cognitive operations involved are often quite complex. Someone observing primary age children playing a board game would probably remark that they succeed even though some of the concepts are in advance of what they are being taught in school. Their success seems to be due to a number of factors: motivational, social and the learning experience inherent in the design of the game.

Now let us imagine a researcher who wants to investigate the same phenomenon in secondary age children. These are older children so it is self evident they will know more. Group work in secondary school is less common, and so it is natural to test them individually. There are lots of different board games, but the rules of chess are very widely known, and chess is an appropriately serious game for children of this age. In order to test a reasonable sample, a pencil and paper test is needed. So the logical way forward is perhaps to give these children a test that consists of a number of chess problems of the kind that appear in the more up-market newspapers (the kind the researcher reads).

When the test results come in, the researcher is appalled to discover how poor secondary age children are at board games. Many of the responses appear very muddled. A few of the children have become fixated on the 'pictures of horses' that appear on the chess board, and the researcher concludes that they are not viewing the problem as a board game at all, but have regressed to seeing it as a picture.

Analogies are always dangerous and this may not be an altogether fair comparison. But it does highlight the very different expectations we have of primary and secondary students, and the different approaches to assessing them. The interpretation of graphical information is a complex, multi-facetted skill and it may not be possible to test it adequately with the sort of questions used to assess arithmetical skills (Berg & Smith, 1994). As Preece & Janvier (1993) have shown, the context of a graph is of great importance, and researchers are not always careful to choose a context that students will engage with. But perhaps the biggest problem is the false assumption that people can instantly engage with the rules that have been used to construct a graphic. Even professional adults, who have encountered a wide range of information graphics, take their time when meeting a new type of graphic. They will often seek reassurance from colleagues that they are seeing the information correctly. Like an unfamiliar board game, there are always rules to be learned.

*Graphs and the Curriculum*

This complicated picture is not easy to apply to the school curriculum, but it would seem that the development of graphical interpretation skills are more likely to be promoted by exposing children to a rich and varied diet of graphical experiences, than by detailed attention to graphical syntax.

In the junior school, the increasing use of computers for information handling is likely to naturally increase children's exposure to information graphics (e.g. Jones, 1993). In the long term this may have a very significant effect in increasing graphical interpretation skills. But there are dangers. As Pratt (1994) points out, it is all too easy with a spreadsheet to call up a graphic which is beautifully drawn but meaningless. Sadly, junior age children do not have the skills to judge whether a graphic makes sense and is worth further effort. Some teachers will have problems with this judgement as well. Perhaps an essential element in any information handling course for teachers is to develop discrimination of meaningful and meaningless graphics. Software that is less open than spread sheets (e.g. EUREKA described by Phillips, 1980) avoids this problem by ensuring that graphics are nearly always meaningful, but it lacks the flexibility of general purpose software like spread sheets.

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