Computer-Aided Graphing: a comparative study

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ABSTRACT Despite the massive investment of time and money in information technology it is difficult to get clear evidence of ‘value-added’ in relation to IT use in our schools. This comparative study was conducted to investigate if there are any advantages to pupils using computer generated graphs as opposed to plotting them manually. The context of the study was a secondary science practical activity involving electrical characteristic graphs. There was evidence that plotting graphs manually not only caused a time penalty but difficulties in drawing the best fit lines reinforced, rather than corrected, misunderstandings about the relationships between the variables. The positive effects noted when using the computer approach seemed to be most significant for younger and less able pupils. The data on pupil-teacher discussions suggested that this was a significant factor in assisting the development of pupils’ interpretation skills whatever approach was adopted. The study was able to make suggestions on the best teaching approach to take when asking pupils to interpret information presented in a graphical form.

Introduction

Although the precise role of practical work in school science continues to be the subject of debate (Woolnough & Allsop, 1985; Hodson, 1993; Wellington, 1994) most science teachers see it as an essential part of science education. Indeed the requirements in the current version of the National Curriculum for Science for England and Wales (Department for Education, 1995) identifies a central role for practical work. In many cases efforts are made to link the data obtained by the pupils during practical investigations with the abstract ideas and concepts of science. An integral part of this process often involves the interpretation of scatter graphs produced using this data.

Until quite recently there was only one graphing option available if pupils had collected the data for themselves, the production of a manually plotted graph. However, it is now possible for computers to both collect and...
plot data for pupils. This raises the question, does a computer-generated graph as opposed to a manually drawn graph change a pupil’s ability to interpret information presented in a graphical form? The research presented here explores this question in some detail.

**Research Data on Graphing**

There is a considerable body of research data on the performance of pupils when using manually drawn graphs. Swatton & Taylor (1994) conducted a survey of pupils’ performance in the area of data interpretation by asking pupils aged 11 and 13 a series of questions about graphical representations. They identified that pupils find it particularly difficult to describe the general relationship between the variables, with only 8% of 13 year old pupils able to give a full description linking two quantities. Austin et al (1991), using data taken from the Assessment of Performance Unit surveys conducted in the early 1980s, confirmed the difficulty pupils have in this area but gave slightly healthier figures; 35% at age 13 rising to 60% at age 15. In another report based on the findings of the APU surveys, Taylor & Swatton (1990), identified the ability to read scales as the single most important factor in determining success in the interpretation of graphs. The APU data showed that performance on a range of graphical interpretation tasks improved as pupils got older. These findings were confirmed by a later study in America (Padilla et al, 1986). However, there is still some cause for concern in view of the importance placed on graphical interpretation in the National Curriculum requirements for science. For example these require pupils to use graphs to identify trends and patterns in results at Key Stage 3 (11 – 14 years) and to identify relationships between variables at Key Stage 4 (14 – 16 years).

There is considerably less data on the effects of computer-aided graphing and most of it comes from studies conducted in America. Significant in this respect is the Microcomputer Based Laboratory Project (MBL): a five year investigation based at the Technical Education Research Centre (TERC) and funded by the American National Science Foundation during the late 1980s (Thornton, 1987). Linn et al (1987) used MBL equipment with eighth grade pupils during an 18 week physical science course which involved 54 temperature and 25 chemistry activities. ‘Students came to class with good knowledge of graph features. MBL improved their ability to identify graph trends and to extract the meaning of the information presented’ (p. 252).

Adams & Shrum (1990) carried out a study on high school biology students to investigate their ability to construct and interpret line graphs. They found a small improvement in the ability of groups using MBL when working on graph-interpretation tasks. Their claims were more muted than those in the earlier study by Mokros & Tinker (1987), who conducted a
three month study as part of the MBL project. They used computer-aided practical work in several areas of the science syllabus and noted significant gains in terms of pupils' graphing skills. In particular they claimed that common 'misconceptions' such as seeing the graph as a picture and slope/height confusions are so easily dispelled by MBL that they are not true misconceptions. Mokros & Tinker suggested there may be four reasons for the success of such computer based work: '... it uses multiple modalities, it pairs real time events with their symbolic representation, it provides a genuine scientific experience and it eliminates the drudgery of graph production' (p. 381).

Manipulating the equipment, experiencing the activity and seeing the physical phenomena change are some of the benefits claimed for practical work in general. However, as suggested above, in the case of computer-aided practical work, pupils have the added benefit of seeing the graphical representation at the same time as the experimental event itself. Phillips (1986) argued that the limitations set by our short-term memory store are overcome when computers are used to present information in the form of graphs. He argued that they are a powerful memory and thinking aid which helps to overcome the limit to the amount of unprocessed information we can memorise or manipulate. He goes on to suggest that: 'the graphical image itself becomes a kind of memory store for as long as our eyes continue to look at it' (p. 39). In addition, Shuell (1986) describes 'contiguity' (the proximity of two events) as a well established fundamental variable affecting traditional types of learning.

Jackson et al (1993) investigated the potential of computer-assisted graphical work with low ability pupils. They used open-ended tasks, based on secondary sources of data, to explore the ability of pupils to interpret, select and purposefully modify graphs. They found not only an improvement in the pupils' abilities in these skills but they also noted other gains, particularly in terms of collaborative working (pupils discussing the meaning of the graphs and jointly solving problems).

One of the few studies to investigate the effects of computer-aided graphing in Britain has been conducted by Pratt (1995) into the effects of extended access to portable computers on primary children's graphing skills as part of the Primary Laptop Project. He made the interesting distinction between what he called active and passive graphing. Passive graphing according to Pratt is when the primary focus is on presentation, whereas active graphing is when the graph is used by pupils to decide on the next action to be taken. He reported: 'Some very young children have been able to make accurate and complete verbal interpretations of their experiments, as mediated by their graphs' (p. 167) [see also Phillips, this issue, Editor].

The findings by Pratt are in stark contrast to the disappointing results for secondary pupils using conventional graphing reported earlier in this
article by Swatton et al and by Austin et al, and tend to support the positive features identified in the American studies.

**Research Question and Methodology**

The following study was conducted to explore the teaching and learning implications of computer-mediated graphing for secondary aged pupils in British schools. Having explored a number of possible approaches during the pilot phase of the research it was decided to conduct a comparative study. This approach was taken in view of the lack of research data in this area. It was felt to be important to compare pupils’ performance when using computer-generated graphs with those involving equivalent manual methods.

In all, 36 pupils working in pairs were involved in the main phase of the study, representing two age groups (Year 8 and Year 10) and three ability bands. The structure of the study is represented by the grouping for the upper band pupils shown in Figure 1.

Figure 1. Nature and number of groups for Upper band Year 8 and 10.

This structure was repeated for Middle and Lower band groups in both Years 8 and 10.

The pupils representing each age group came from different schools, in both cases a mixed comprehensive school. The criteria for the selection of pupils was that the three pairs representing each ability band (Upper, Middle and Lower) were as far as possible equivalent in their scientific background and ability and were representative of that ability band. For Year 10 pupils, selection was on the basis of National Curriculum levels. For the Year 8 pupils a common test was used for the whole year group and this was used to identify three pairs of pupils to represent each ability band.

The curriculum area chosen was electrical characteristic measurements. The computer based approach can be done using a computer interface called a Current-Voltage Module. A description of this module, which pupils can use to plot the electrical characteristics of components such as bulbs and
resistors on the computer screen, is contained in Barton (1990). This curriculum area had a number of advantages for the research envisaged:

- no previous data-logging research had been done in this topic area;
- the equipment is portable and inexpensive;
- the topic is an important part of the National Curriculum requirements in England and Wales;
- it was possible to create equivalent conventional practical activities for comparison;
- the interpretation of information in a graphical form is a central part of this area of work;
- the independent variable was not ‘time’ as had been the case in almost all other data-logging research reported.

Pupils were extracted from their normal lessons and worked with the author for the equivalent of one double period. All three groups in each ability band were set the same task, the only difference being the method used to collect the data. The computer groups used the Current-Voltage interface described earlier, the practical groups recorded data by reading the scales on digital voltmeters and ammeters and the non-practical groups were supplied with the necessary data. The ethical consideration of depriving pupils’ access to the other two methods was not considered to be significant due to the limited time scale of the intervention.

To make the comparisons valid a script was used, which provided the same prompt questions and working order for each group. The activities chosen, which included extracting data from graphs, sketch graph predictions and the identification of concealed components, were designed to provide a rich medium to investigate the effect of the computer on graphical interpretation skills.

Each session was videotaped and pupils produced records of their work in the form of graphs and written statements. The analysis adopted consisted of a combination of quantitative and qualitative approaches. These were chosen to provide complementary insights. The quantitative approach was intended to provide an overall comparison of the three methods in terms of the amount of time spent on various activities. The qualitative approach, analysing key sections of transcripts from each session, was intended to give a detailed picture of pupils’ attempts to interpret the graphs.

To obtain the quantitative comparison of each session, a category analysis was carried out. This was done by viewing the videotape of each session and placing the activity during each 30 second interval (using the ‘on-screen’ clock) into one of five categories. The categories used were:

- pupils collecting data
- pupils processing data
- pupil making graphical predictions
- teacher giving explanation or information
teacher led questions
To test for inter-observer reliability in the allocation of these categories, a Head of Science in a comprehensive school, not used in this research, applied the categories to a random sample of the data. The overall level of agreement was 90%, which was considered to be satisfactory.

The qualitative data was provided partly by observation of the videotapes but also involved the analysis of key sections of transcripts. The use of tape transcripts have been criticised for possible lack of objectivity but it is significant that in this study transcripts could be selected from the three sessions to illustrate the relative performance of pupils. The detailed analysis of tape transcripts provided the opportunity to investigate the effects of discussion on pupils' ability to interpret graphical data. An important additional source of data was provided by the written records and graphs produced by the pupils during the sessions.

Analysis
The main findings of the research can be grouped into four areas:

x comparison of the activities during each session
x features of each method used
x the relative performance of each group on graphical interpretation
x teacher's role

I will deal with each of these in turn by providing extracts of the supporting evidence and summarising the main findings. Since most of the data involves three sets of tape transcripts, it is difficult to provide anything other than brief samples of data to support the conclusions drawn.

Comparison of the Activities During Each Session
The category analysis of the three methods used revealed clear, if not unsurprising, results. Pupils spent between two and four times longer producing graphs manually than those using the computer. The disparity between the computer and the manual approach being most significant for Year 8 pupils. Pupils using the computers spent the largest proportion of their time involved in question and answer sessions with the teacher, whilst those using manual methods spent most of their time processing data.

Features of Each Method Used
From the videotape record of each session and the analysis of the graphs produced by the groups, a comparative picture of the effects of using each method was obtained.

For those using manual methods to produce a graph, only the Middle and Upper band Year 10 pupils were able to complete the exercise unaided
and with a good chance of success, although error free graphs were very rare even here. There were problems with all aspects of graph production which culminated in the production of poor best fit lines. In almost all cases pupils assumed that graphs would produce a straight line relationship. This belief was a powerful influence when pupils made decisions about the shape of the best fit line. The tendency to gravitate towards linearity had been noted by Leinhardt et al (1990) and similar observations were noted in the APU data (Archenhold et al, 1991) in which almost all pupils drew straight lines for data points which showed a curvilinear relationship.

Once individual points have been plotted it is sometimes possible for a range of alternative lines to be legitimately drawn through the points. This choice may well be influenced by prior experiences, i.e. the expectation that the data will form a straight line. In this way it could be argued that manual plotting places an additional burden on pupils, since they are required to try to set aside their pre-conceived ideas to plot the best fit line before they move on to interpret the meaning of the graph they have plotted. Pupils using the computer are equally likely to expect straight line relationships but they have the benefit of seeing the graph produced on the computer screen before moving on to try to interpret the shape of the graph.

Pupils using the computer displayed a clear reaction to any unexpected data as it appeared on the screen. They also tended to make spontaneous links with previous knowledge. At no stage in the research were equivalent reactions seen when pupils were either plotting or analysing manually drawn graphs. An example of this reaction and linking to previous knowledge is demonstrated by the following transcript from a pair of Year 9 pupils (obtained during the pilot study). The pupils were given a device new to them (a diode) which was concealed from them in a ‘black box’.

As the diode started to conduct:

Pupil 1 Oh my gosh.
Pupil 2 An upside down bulb.
Teacher Do you want to fill in some of those points?
Pupil 1 I didn’t think it was going to go like that.
Pupil 2 It can’t be a resistor, they go straight.
Pupil 1 It can’t be a bulb because it hasn’t got that part in, (points to the screen).
Teacher So how would you describe it? Think about what it’s doing. You know a bit more about current now.
Pupil 2 There’s not much current going into it then suddenly it goes up – there’s loads of current.
Teacher Is it a good conductor to start with?
Pupil 1 & 2 No.

Discussion goes on to the fact that it becomes a good conductor only after a certain voltage is reached.
Using data from tape transcripts together with graphs produced by the pupils during the sessions, the following conclusions were made:

- manual graph plotting is a problem for all, but particularly for the least able
- best fit lines are a particular problem in manual plotting
- real-time plotting on the computer screen stimulates pupils to provide explanations and to make predictions

The Relative Performance of Each Group on Graphical Interpretation

For each group this was investigated by comparing pupils’ ability to provide qualitative descriptions of graphs, their ability to interpret data, their ability to make graphical predictions and their ability to describe the general relationships between variables. The main source of data for this analysis was provided by comparing pupils’ responses to common prompt questions.

For the Upper and Middle Band Year 10 pupils there was little difference between the three groups in this area. Differences were noted for younger and less able pupils. This is illustrated by the following extracts from the summary discussion at the end of the session for the Year 8 Middle Band pupils:

Group 1: (computer)
Pupil Bulbs bent, resistor goes in a straight line. The resistance is all the same along the way. ‘Cos the bulbs bent they are all different numbers.

Group 2: (practical)
Pupil If it’s a graph for a resistor it’s more of a straight line. The bulb is more horizontal.

Group 3: (non-practical)
Pupil Resistor does a straight line. Bulb goes straight then down. The resistor always keeps the same number. Bulb changes down.

Only the computer group were able to link the change in resistance for the bulb directly to the shape of the line. The link between resistance and the shape of the graph, for the resistor, was made by both the computer group and the non-practical group but again the use of the phrase ‘is all the same along the way’, by a pupil using the computer, more explicitly links constant resistance to the shape of the graph.

Pupils using manual methods in both year groups joined individual points together with a series of straight lines. There are a number of references in the literature to the problems associated with ‘pointwise’ collection of data in which the graph seen as a collection of isolated points rather than an object or conceptual entity (Leinhardt et al, 1990; Bell et al, 1987; Austin et al, 1991). It may be that since these pupils see the data as a
series of individual numbers, they are less likely to see them as part of a continuous relationship between the two variables. The fact that pupils are seen to concentrate very hard on manual graph plotting seems to emphasise the significance of the individual points, particularly for the least able. As pupils struggled to locate points on a sheet of graph paper there seemed to be little sense of a relationship emerging between the two variables. These problems are all the more significant in view of the importance placed on the use of best fit lines in the National Curriculum requirement at Key Stage 3 and 4 (Department for Education, 1995 p. 16 & p. 27).

Using data from tape transcripts, as pupils were asked common questions on graphical interpretation, the following conclusions were made:

- for Year 10 pupils of average ability and above, there were no major differences in pupils’ ability to interpret graphical data using the different methods
- where differences did occur the extra material covered by the computer groups resulted in their interpretations containing more detail
- handing the equipment didn’t seem to make any difference to pupils’ ability to interpret the graphs
- computer groups tended to talk about the shapes of the graphs
- manual plotting tended to emphasise individual data items rather than the continuous nature of the relationship between the variables
- describing graphs is much more effective when a second graph is present
- no advantages were observed associated with manual graph plotting

The Teacher’s Role

What are the messages about teacher-pupil interactions which emerge from this study? The first one is perhaps the simplest and most obvious; just the act of talking to pupils about graphs improves their ability to describe them and encourages them to reflect on their meaning. Talking to pupils in this context usually means the use of questions or prompts of some kind. Teacher led questions was one of the categories used in the analysis and the videotape transcripts provided a rich source of data on this topic. As discussed earlier the use of the computer increases significantly the time available for such discussions to take place.

The idea of ‘scaffolding’ introduced by Bruner and its development by Mercer (1995, p. 1) who coined the term ‘the guided construction of knowledge’, provided a context in which to investigate the teacher’s role. This is illustrated in the following extract from the pilot study data. The Year 9 pupils had correctly drawn a sketch graph to predict the shape of the resistance v voltage graph for a resistor. As they watch the actual graph emerge on the computer screen:

Pupil 2  It’s going horizontal – going close together.
Teacher  Is that what you thought? What happens to the resistance
as the voltage changes?

Pupil 1  Resistance is less.
Pupil 2  The higher the voltage the smaller the resistance.
Teacher  Is that what a horizontal line tells you?
Pupil 1  Means it stays the same.
Teacher  Come on you have told me two different things – get your
story straight. What does a straight line tell us about resistance?
Pupil 2  It is the same however the amount of voltage.

This indicates the importance of the teacher involvement at this stage. For these pupils, simply seeing a confirmation of their correct prediction would not have been sufficient in this case.

The following transcript, again from a pair of Year 9 pupils, relates to a difference in the behaviour of a bulb when the current is increasing or decreasing. This produces the graph shown in Figure 2.

This effect, due to changes in the temperature of the bulb, is not observed when using electrical meters since the bulb has time to cool before the current is recorded. The pupils had noticed this effect which prompted the following exchange:

Teacher  Were you watching the bulb itself when you were doing this?
Pupil 2  Well for a long while you can’t see anything and then
(watches whilst other pupil adjust the voltage)
Teacher  And then ..?
Pupil 2  It goes red not white.
Teacher  Were you looking at the screen at the same time?
Pupil 2  Oh (holds up the bulb and watches the screen) . When it
really gets to glow brighter it isn’t as good at all, when it
really starts to glow. It resists a lot more that’s why it’s
making the heat and light.
Teacher  Right.
Pupil 2 But a little bit passes out that wire so you don’t notice it as much. Let’s look on the way down and on the way up. On the way up… On the way down it’s glowing a little bit more still as the electricity is getting less that’s why (points to the trace on the screen) it isn’t as good at passing the current through on the way down.

Teacher Right so on the way down it’s a worse conductor than on the way up, yes?

Pupil 2 (nodding)

The transcript shows the importance of the teacher’s intervention and the benefit of the ability to re-live the real-time presentation of data. Notice the way in which the data on the screen encouraged pupils to give explanations and to make predictions, e.g. ‘It resists a lot more that’s why it’s making the heat and light’.

Using tape transcripts of pupil-teacher interactions, the following conclusions were made:

x irrespective of the method used the intervention of the ‘teacher’ was crucial
x talk is a vital ingredient in graphical interpretation
x the combination of real-time display of data and prompt questions from the teacher was a potent combination to assist pupils when interpreting graphical information

Review of the Methodology

It is useful to consider the extent to which the specific context of the study could limit the application of the findings. At this stage it is important to re-state that the discussions reported were conducted in the context a teacher working exclusively with a one pair of pupils. Although this does not reflect the complex interactions usually associated with whole class activities it should provide, in a rather concentrated form, indications of the possible interactions between pupils and teachers. However, a study of this type is not appropriate to effectively probe pupil-pupil discussion due to the close proximity of the teacher throughout the session.

Messages for Teachers from the Study

The study not only highlighted the difficulties associated with manual plotting but identified the context in which computer-generated graphing could prove to be effective. As identified earlier, the ability to interpret data as it is collected proved to be motivating and stimulated pupils to provide analysis and prediction. The main points for teachers are:

x The computer approach appears to be superior to the non-practical approach since it is more flexible and offers real-time plotting. It allows
more investigations to be conducted and gives pupils the option of extending the investigation by collecting new data.

- Manual graph plotting should be avoided when the main aim is to interpret relationships via graphical analysis, particularly for younger and less able pupils. It causes a serious time penalty and results in pupils focusing on individual data items rather than the continuous relationship between the variables.

- Sketch graph predictions, followed by plotting data for confirmation, has proved to be effective in promoting discussion. Due to the small time between prediction and the final graph being plotted, the computer approach is particularly appropriate.

- Wherever possible teachers should engage pupils in discussions on the meaning of graphical data. Teachers should encourage pupils to discuss their ideas.

**Implications of the Study**

One of the difficulties faced in conducting research in areas involving the use of information technology is the pace with which new hardware and software developments occur. Developments over the past few years have made the hardware and software used in this study and in the MBL project in America look very primitive. Rogers (1995) discussed a number of these new developments, for example the ways in which simply reading data values from the graph can be extended to include gradients, areas and differences. He went on to describe more sophisticated features such as the ability to plot derived quantities such as rates of change, curve fitting options to give the best fit lines to the data collected using several types of functions.

The study indicated that computer-assisted graphing was particularly effective for the younger and least able pupils. However, the very simple presentation software was used to simply plot the graph, what was described earlier by Pratt as passive graphing. It is sensible to assume that this approach would be of particular benefit to pupils who experienced most difficulty in manually plotting graphs. So where does this leave advanced level and above average GCSE pupils? At this level the difficulties of producing manual plots is not as significant. However, manual methods impinge on current practice in other ways. For example if non-linear functions are investigated then either they are treated qualitatively or are linearized by use of a suitable function, e.g. the use of log plots to obtain a straight line for functions such as $y = ax^n$. The facilities now exist, as discussed above, to investigate the coefficients of such functions in a much more active way. This would provide a more direct relationship between the mathematical description of functions and their graphical representation. Clearly the potential exists to change the nature of practical work for pupils.
at advanced level every bit as much as simple graphing software opened new possibilities for the less able 13 year old pupils in this study.

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References


