AN ANALYSIS OF GRAPHS IN SCHOOL TEXTBOOKS

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We present here an analysis of school textbooks with graphs and related activities as the point of focus. The sample textbooks that we have considered for the analysis are NCERT textbooks (from Grade 5 to Grade 10, in the subjects of Science, Mathematics and Social Sciences). A quantitative analysis is done on frequency of occurrence, types and features of the graphs present in the different textbooks. We observe that the graphs are under-represented in the school textbooks. Considering the importance of the ability to read, construct and interpret graphs in science and mathematics education we recommend strongly that in the future edition of textbooks graphs should be properly represented.

Keywords: Critical graphicacy, Textbook analysis, Graphs

INTRODUCTION

Inscription is a term used by Latour, to describe representations other than text in scientific communication. Inscriptions include sketches, photographs, diagrams, maps, plans, charts, graphs and other non-textual, two dimensional formats (Latour & Woolgar, 1986). Graphicacy is an ability to read graphical inscriptions, just as literacy is an ability to read written text. Graphicacy is defined as the ability to understand and present information in the form of inscriptions (Aldrich & Sheppard, 2000). In *Critical graphicacy* (Roth, Pozzer-Ardenghi, & Han, 2005), the authors address some overarching question about graphicacy: 'What practices are required for reading inscriptions?' and 'Do textbooks allow students to develop levels of graphicacy required to *critically* read scientific texts? In the book *Critical graphicacy* Roth states:

…our aim as critical educators is not just the provision of opportunities for students to become graphically literate; rather, we want students to develop critical graphicacy, that is, we want them to become literate in constructing and deconstructing inscriptions, the deployment of which is always inherently political (Roth et al., 2005, p. 241).

Just like literacy and numeracy, graphicacy is gaining an important role from the primary level (Aldrich & Sheppard, 2000). In the various graphical formats that are included in the broad umbrella of graphicacy we have focused on the graphs. Graphs here would mean the Cartesian graph and statistical graphs. The rationale for choosing this particular facet of graphicacy is elaborated below. In the currently expanding multi-media culture we find popular media like television, newspapers, magazines, internet use graphs widely. Graphs are frequently used for practical purposes, from making historical information accessible and memorable to helping decision-makers comprehend relevant data (Shah & Hoeffner, 2002). Processing information in our highly technological society depends upon a reader's ability to comprehend graphs (Curcio, 1987). But even with the widespread use of graphs in the media the process of comprehension of graphs can be quite demanding and prone to errors. School children, and even adults, commonly make systematic errors in interpreting graphs, especially when graphs do not explicitly depict the relevant quantitative information (Shah & Hoeffner, 2002).

The other problem with graphs is with the design of the graphs themselves. Tufte in his series of excellent books on graphic design gives a lot of examples of good as well as bad design of graphs in popular and scientific media (Tufte, 1997, 2001, 2005; Wainer, 1997). The graphic format can have a profound influence on viewers' interpretations, even in familiar domains, for relatively complex interpretation tasks (Shah, Mayer, & Hegarty, 1999). Tufte in his books has provided principles for presenting data in visually economical, accurate and effective ways. The principles relate to various aspects of visual display of information.

Graphs in the school level appear in subjects like science, mathematics and social sciences, though the use of the graphs varies from subject to subject. In science graphs have two main functions: one is to show the relation between two quantities in a parsimonious and economical way and other is to present data in a comprehensible and meaningful format. Reading and writing graphs is an inter-disciplinary skill. In the social sciences, at least at the school level, the use of graphs is limited to show various statistics. In mathematics the graphs are used with the idea of function. Functions and graphs represent one of the earliest points in mathematics at which a student uses one symbolic system to expand and understand algebraic functions and their graphs, data patterns and their graphs, etc. (Leinhardt, Zaslavsky, & Stein, 1990). Studies show that the presence of graphs in research journals is related to the perceived 'hardness' or 'softness' of sciences. The number to graphs are higher in 'hard' science subjects like physics or chemistry and the number of graphs for 'soft' sciences like sociology or economics are significantly less (Cleveland, 1984; Smith, Best, Stubbs, Johnston, & Archibald, 2000). The idea of a 'hard science' is when we present graphs in an article, it implies that [a] the data is quantitative and [b] expressible in a mathematical form.

In mathematics and science education, functions and graphs serve different purposes. A mathematical perspective of the notion of functions and graphs regards the understanding of the underlying formal and abstract mathematical concepts as the main objective. Even when examples from 'real' world are taken, they are used to deepen the students' understanding of more abstract mathematical concepts. Science educators on the other hand use graphs as representations of 'real' observations and as analytic tools, which enable the observer to learn about the phenomenon displayed (Leinhardt et al., 1990). An example of early use of graphs for representing phenomenon is the Small Science curriculum in which activities are introduced in grades 1 and 2, and graphs themselves in grade 4 (Ramadas, 2001). It has been suggested in the National Curriculum Framework of 2005 for emphasis on making connections between mathematics and other subjects. When students learn to draw graphs the functional relationships in science are to be emphasized (NCF, 2005).

Comprehending and Construction of Graphs

We now present some of the problems which are faced by students while comprehending or constructing graphs. For graphs we have two distinct categories which relate to their understanding viz. comprehension and construction. Studies have been conducted which list the alternative conceptions that students have in these two regards. The study of Leinhardt, et al. (1990) focuses on the difficulties that students have regarding the comprehension of graphs. The study classified students' difficulties in this area into four kinds of categories: [a] confusing the slope and the height; [b] confusing an interval and a point; [c] considering a graph as a picture or a map; [d] conceiving a graph as constructed of discrete points. Similar findings are also reported in the work done in the context of physics (Beichner, 1994; McDermott, Rosenquist, & Van Zee, 1987). The study by Mevarech and Kramasky (1997) presents students' alternative conceptions related to construction of graphs. They report three major categories in this regard: [a] constructing an entire graph as one single point; [b] constructing a series of graphs, each representing one factor from the relevant data; [c] conserving the form of an increasing function under all conditions.

The studies on the graph perception imply that certain graphical designs are perceived more easily than others. Studies by Cleveland and McGill (1984, 1985) provide a list of the most relevant features in reading of graphs. The review work by Shah, Freedman, and Vekiri (2005) describes the influence of display characteristics [e.g. line graphs vs. bar graphs], data complexity, and task on graph interpretation. The effect of individual differences and developmental factors like graphical literacy skills, content knowledge, visuospatial abilities and working memory influence graph comprehension is also described.

Our Study

With this preliminary review of literature related to the topic of graphs in science and mathematics education we now present our study.

The present article reports the first phase of a larger work, on graphs at school level. If the subjects in the school education like science, mathematics, and humanities do not include a reflexive component that allows students to critically evaluate the knowledge claims, they will always be subject to some form of indoctrination (Roth et al., 2005). As the National Curriculum Framework 2005 (NCERT, 2005) aptly puts: *Science education in India, even at its best, develops competence but does not encourage inventiveness and creativity…inquiry skills should be supported by language, design and qualitative skills. Schools should place much greater emphasis on co-curricular activities aimed at stimulating investigative ability, inventiveness and creativity, even if these are not part of the graduating exam.*

In the study that we have proposed we consider the graphs in the school textbooks as the main problem of our study. Graphs have a limited and often secondary use in the textbooks. We want to elaborate on this particular aspect in the present article. The first part of the work is to locate the presence of graphs and related activities in the textbook sample that we have chosen. The term graphs and graph related activities would mean all the places where line graphs [Cartesian], bar graphs, pie charts or graphs otherwise are used or mentioned.

Sample and Methodology

The textbooks used for teaching form an integral part of an educational system. In the Indian educational system the state prescribed textbooks are mostly used in the classroom. The textbooks provided by the state hold a central place in the Indian educational system. This gives rise to a "textbook culture", a term elaborated by Krishna Kumar (Kumar, 1988). With above mentioned central role that the textbooks play in the educational system, it becomes imperative that the textbooks are well structured in their content and delivery. In India the National Council for Educational Research and Training (NCERT) is the highest body which publishes and prescribes the curriculum. All other state and other boards are supposed to follow the framework produced by the NCERT. Most of the textbooks produced by the different state boards derive their form and content from the NCERT textbooks. In other words, NCERT textbooks are used as a framework for making other textbooks. So if we cover NCERT books in an analysis we would have a wide coverage of the curriculum that is followed in India. For this reason we have chosen the NCERT textbooks in our analysis. We have covered all the books except the languages from Grade 5 to 10. In each grade we have analysed following books: Grade 5 two books, Grade 6 four books, Grade 7 five books, Grade 8 five books, Grade 9 six books and Grade 10 six books. This takes the total number of books in our sample to 28. We have chosen all the subjects except the languages as we consider the ability to write and interpret graphs as inter-disciplinary skill, not limited to one particular subject. We want to see the way graphs are used *across* the grades and *across* the subjects.

A study of literature reveals the different modes of analysis that have been done for analysing textbooks. Both qualitative and quantitative techniques are used. Quantitative techniques are mainly used in terms of space and frequency as reported in (Pingle, 1999). This can be quantification of how many times a particular word appears in the text, how much space has been allocated for a particular theme, event or topic. Quantitative methods are best suited for analysing large samples. With these methods we are able to cover a large area, as Pingle (1999) suggests '[quantitative methods tell] us a great deal about where the emphasis lies, about selection criteria, but nothing [in themselves] about values and interpretation'. In qualitative research the analysis tends to be deeper in terms of structure of the textbook. In our own analysis we used both quantitative and qualitative techniques. The qualitative and the quantitative analysis complement each other.

We wanted to get a trend of the presence of graphs in the textbooks. The trends thus obtained would give us an idea about the use of graphs, and possible use of graphs (when absent). Therefore the analysis was conducted by raising the following questions. What are the different types of graphs that are present in the textbooks? What is the frequency and trend of the occurrence of graphs in the textbooks, across grades and across subjects? Is there any subject wise preference to presence of graphs in the textbooks? The meta-data that we have added in the database includes the following parameters: *Grade, Subject, Chapter, Page Number, Figure Number, Legend, Caption, Graph Type, Description /Data, Comments*. We have included a figure in the textbook in the sample when it uses graphs in some way or other. For example in mathematics we have included the use of number line to teach the basic operations of arithmetic as one occurrence of the graph.

Results and Trends

In this section we present some of the results of the quantitative analysis of the data that we have obtained so far. We have categorised the subjects in three major groups, Science, Mathematics and the Social Sciences. The Social Science group includes Geography, Environmental Science, Political Science and Sociology in the grades 8 and above.

We obtained the frequency graphs in each of these subjects, across all the grades under consideration. In Figure 1 the variation of the total number of graphs is shown with the grades. The stacked bar graph also shows the number of graphs as per the subjects. One would expect that the total number of graphs in the textbooks would increase with the grades, that is, higher grades will have more number of graphs. But no such clear trend is seen in the sample that we have analysed.

We now present the types of graphs which appear in the school textbooks. Figure 2 shows another version of Figure 1, in this Figure the distribution of different types of graphs across the grades is shown. The major categories that we have used in this are the line graphs, bar graphs, pie charts and others. Most of the graphs that are present fall in the following three categories: line graphs, bar graphs and pie charts. By line graph we mean a Cartesian graph. When a bar graph and a line graph are simultaneously present in a figure we have included them in the line graph category. In mathematics, especially in grades 6 and 7, the number line has been used extensively to teach the concepts of addition, subtraction and multiplication of real numbers and integers. The number line is included in our category of line graphs. The category 'others' includes graphics which are of graphical nature but do not fall clearly in either of the three categories mentioned above.

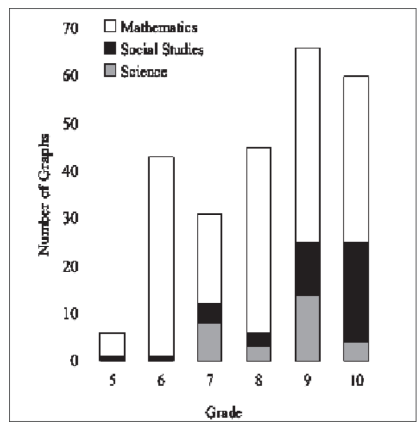

Figure 1: Variation of total number of graphs with grades

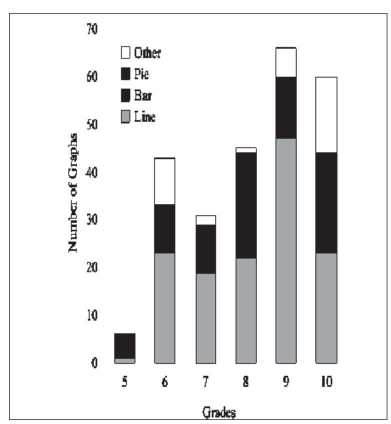

Figure 2: Different types of graphs across grades

The nature of stacked bar graphs makes it hard to make inferences on the variation of variables, except for the one which is at the bottom. In Figure 1, one can only effectively compare the trends in science textbooks, across grades. For the other two categories, namely social studies and mathematics the baselines for comparison don't match. So it is hard to infer trends directly. To overcome this problem we have plotted the total number of graphs in each subject as a function of grades in the Figures 3, 4 and 5 for science, social studies and mathematics respectively.

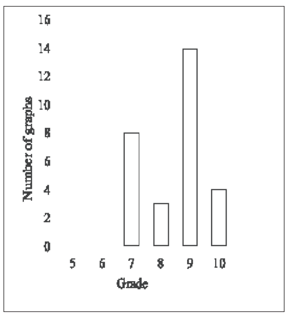

Figure 3: Variation of total number of graphs with grades for science textbooks

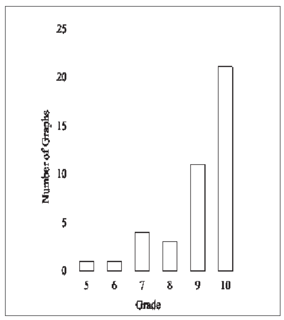

Figure 4: Variation of total number of graphs with grades for social studies textbooks

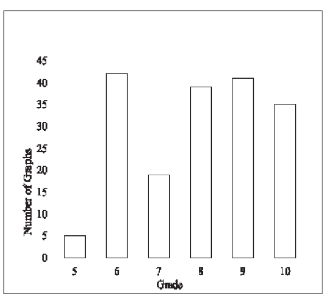

Figure 5: Variation of total number of graphs grades for mathematics textbooks

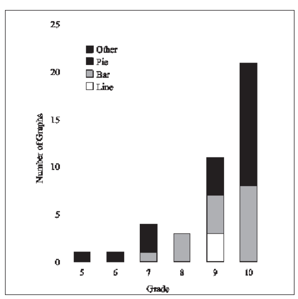

Figure 6: Different types of graphs across grades with for social studies

In this format of display the only noticeable trend comes in the social studies group, see Figure 4. Here we have a clear increase in the number of graphs with the grades. In Figure 3 and Figure 5 for science and mathematics textbooks this increase in the number of graphs is not seen. In fact in the science textbooks the total number of graphs substantially decreases in grade 10. In mathematics textbooks on the other hand, the total number of graphs do not vary this much, at least in the last three grades.

The rest of the article we will focus on the trends in science textbooks. The total number of graphs is the least in case of science, totaling to 29, whereas for social studies and mathematics it is 41 and 181 respectively. This is one clear indication that the school science textbooks need content which would address the issue of graphs. Of these 29 graphs, 27 are line graphs, and the other two are bar graphs and pie chart. Thus we see a trend that science textbooks mostly use line graphs, even if used sparingly. We see that in the science textbooks grade 9 has the maximum number (14) of graphs. The unit on motion is introduced in grade 9. Most of the line graphs appear in that context. The grade 7 textbook of science has graphs which are also present in the chapter on motion.

In the social studies textbooks we see almost an exponential increase in the total number of graphs as the grades increase. This is a welcome sign. Figure 6 shows a stacked bar graph for the types of graphs that are present in the social studies textbooks across the grades. Here we notice that the bulk of the graphs are statistical in nature: out of the 41 graphs 35 are bar graphs and pie charts. In social studies mostly the graphs have been used to display data.

In the mathematics textbooks line graphs are the most frequent ones to appear, 106 out of total 181 graphs are line graphs. Most of them are concerned with either the arithmetic operations using the number line or developing concepts in the Cartesian coordinate system. Only in the grade 10 the concept of functions using the graph is introduced. In the mathematics textbooks there are chapters on 'Data Handling', which talk about statistical graphs like pie charts, bar graphs, histograms etc.

Conclusion

We have noticed that in the science textbooks, the presence of graphs is very limited. Reading, writing and understanding graphs being an important skill in science, this trend needs to be changed. We see that there exists a tremendous opportunity to explore and utilize this particular aspect of graphicacy in the sample of textbooks that we have studied. Curcio puts it effectively as: "Elementary school children should be actively involved in collecting "real world" data to construct their own simple graphs" (Curcio, 1987). In this case the students will collect "real world" data and use graphs to analyze this data. In this way one can introduce some aspects of critical graphicacy in the classroom. Mere presence of graphs in the textbook doesn't justify its presence unless it is appropriately related to the subject matter. Therefore we need to conduct a qualitative study of context in which graphs appear in the textbooks.

For the qualitative analysis we need to address the following questions: What function does the graph serve in the textbook? We have also looked at the context in which the graphs appear in the textbook. Whether the graphs are referred to in the text, how well are they integrated with the overall text and is any real data used in making the graphs. Does the graph link to any everyday experience of the students? This part of the work will provide a critical analysis of the textbooks with graphical practices being the point of focus. Apart from these considerations we have also looked in the design aspects of graphs. Some of the questions that we pose in this part are: Does it have a good data-ink ratio? Does it have chart junk? The concepts of data-ink ratio and chart junk are well elaborated by Tufte and Wainer in their books on information design (Tufte, 1997, 2001, 2005; Wainer, 1997). In addition to the quantitative study reported in this paper, the nature of qualitative study will help us in giving more normative criteria for the presentation of graphs in the textbooks. There is a major requirement for reconsidering how the graphs are presented and utilized in the science textbooks. Given the existence of a "textbook culture" in India, and the importance of graphs, the trends that we have observed in the textbooks are worrisome. A proper recommendation for integrating graphical content could then be framed considering the need for critical graphicacy in science and mathematics education.

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