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The Interpretation of Graphs: reflecting on contextual aspects

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Abstract. Considering the wide utilization of graphs in different contexts of the contemporary society, curriculum makers around the world have included graphing as a topic in all levels of school mathematics in order to strengthen the social role of the school curriculum. This inclusion has been justified as a way to provide opportunities for students to use mathematical and statistical tools learnt in school to understand out-of-school uses of data. This paper discusses some aspects of the socio-historical origins of graphs and some current contexts in which they are used, as well as pedagogical implications.

Resumo. Considerando a ampla utilização de gráficos em diferentes contextos da sociedade contemporânea, curriculistas de diversas partes do mundo incluíram o ensino de gráficos como tópico de todos os níveis escolares. Essa inclusão tem como objetivo a atualização o papel social de conteúdos escolares relacionados a Matemática e a Estatística. Além disso, essa inclusão tem sido justificada como uma maneira de proporcionar oportunidades para os alunos usarem ferramentas matemáticas e estatísticas para interpretar e compreender dados em situações em situações cotidianas fora da escola. Este artigo discute alguns aspectos das origens sócio-históricas de gráficos e alguns contextos atuais nos quais eles são usados, incluindo implicações pedagógicas de tais reflexões.

Keywords: interpretation of graphs; historical aspects related to graphs; mathematics education; statistics education.

Palavras-chave: interpretação de gráficos; aspectos históricos de gráficos; educação matemática; educação estatística.

1. Introduction

Statistical graphs are one of the most commonly used representations to handle and display quantitative and qualitative data for various purposes. Considering this wide utilization of graphs in different contexts of the contemporary society, curriculum makers around the world have included graphing as a topic in all levels of school mathematics in order to strengthen the social role of the school curriculum (AINLEY; MONTEIRO, 2008). This inclusion has been justified as a way to provide opportunities for students to use mathematical and statistical tools learnt in school to understand out-of-school uses of data (e.g. BRASIL, 1997).

In this paper we discuss some aspects of the socio-historical origins of graphs and some current contexts in which they are used. We would like to reflect on the importance of making explicit the perspectives on which conceptualizations of the interpretation of graphs are based, and address issues related to the differentiation of school contexts from other contexts in which people interpret graphs.

2. Some historical aspects for contextualization

Several studies have emphasised consideration of historical processes related to specific mathematical topics, which might help to understand why and how they are taught and learnt (ARCAVI, 1991). As mathematical and statistical constructs, graphs have specific origins which are related to their use and development in specific historical contexts.

From a socio-historical perspective, graphs can be conceptualised as kinds of tools which are involved in shared symbolic meaning (VYGOTSKY, 1978). Graphs as a human invention mediate human psychological processes, such as memory, comparison, description, choice, and communication. Therefore, the interpretation of graphs can be viewed as a mediated activity in which individuals use graphs to communicate data, and amplify their possibilities for action on the world (LERMAN, 1996).

As cultural mediators, graphs were developed over centuries in different socio-cultural contexts. Kuhn (1962) discusses a direct ancestor of current graphs which was initially developed by Oresme (1320-1382). According to Kuhn, Oresme invented a new paradigm in which graphical representations assumed an important role in presenting phenomena. However, a fundamental step in the use of graphs happened in the seventeenth century with the development of Cartesian systems (BIDERMAN, 1989). Cartesian graphs began to have wider utilisation in academic situations as a mathematical resource which provided the presentation of abundant experiments in different scientific areas.

In the 18th century, Statistics emerged as a new knowledge field and promoted the use of other kinds of graphs associated with official resources which enabled governments to emphasise social and economical outcomes (CARVALHO, 2001). During the Industrial Revolution, Statistics became a vital resource for capitalists who needed to analyse incomes.

William Playfair is acknowledged as an important developer of statistical graphs because his pioneer publication *The Commercial and Political Atlas* (PLAYFAIR, 1786) that comprised 44 graphs, including one of the first statistical bar graphs. In contrast to Cartesian graphs which were used to present results of experiments (TILLING, 1975), Playfair's graphs could spatially describe non-spatial quantities (BIRDEMAN, 1989). For instance, his bar graphs expressed the revenues and expenses of Scotland, in which space was not a variable.

Although Playfair graphed data with very professional techniques and devices (e.g. use of colours and precision of measures of the bars or sectors), he had the pragmatic purpose of facilitating the work of busy businessmen. He believed that his graphs could quickly show information which might take days to be read if it was presented by tables. Birdeman (1989) states that Playfair was more a skilled draughtsman than an academic but his graphs were prototypes for modern statistical graphs.

Cartesian graphs and the first statistical graphs were different because each one had a specific relationship to the domain of Mathematics. On the one hand, Cartesian graphs used by 18^{th} century scientists served to present results of experiments which confirmed general scientific principles expressible as a mathematical function (TILLING, 1975). On the other hand, early statistics graphs did not display the mathematics applicable to data, but they used mathematics to facilitate the visual display of data (BIDERMAN, 1989) in publications for non-scientist readers.

However, both graphical approaches seemed to have as a principal the perspective that the graph itself would present the data which was intended to be displayed by whoever constructed the graph. Therefore, interpretation would be a quick and efficient extraction of information from the graph.

Carvalho (2001) argues that statistics gradually developed from the status of official resources generated by governments, and systematic approaches based on probabilistic theoretical perspectives promoted the development of inferential statistics. In the 19^{th} century, Pearson (1857-1936) and Galton (1822-1911) developed aspects of statistics which made possible the application of graphical forms related to abstract universal as well as idiographic principles. The development of different areas and approaches to statistics also added possibilities for the use of graphs.

In current society, graphs are being used in different contexts which attribute different purposes and meanings to them. A number of studies have investigated different kinds of contemporary contexts for the use of graphs. Wild and Pfannkuch (1999) suggest that in *enquiry contexts* people act as 'data producers' and usually have to interpret their own data and report their findings using graphs (e.g. researchers and statisticians). Gal (2002) labelled as *reading contexts* those everyday situations in which people see and interpret graphs (e.g. watching TV, reading newspapers, looking at advertisements while shopping, visiting internet sites etc). *Reading contexts* are related to situations in which people are interacting with 'media' or 'mass communication' which is associated with social vehicles of communication such as: radio, television, and print publications with large numbers of copies. Other important contexts in which interpretations of graphs are developed are *school contexts* (e.g. MONTEIRO; AINLEY, 2003). In these contexts the interpretations acquire specific characteristics which make them different from *enquiry* and *reading contexts*. For example, when graphs are used in the context of mathematics and statistics classrooms, they are generally associated with intentional aims to teach school subjects.

Gal (2002) states that the differentiation of contexts does not necessary mean that each one is homogenously defined because individuals can develop different types of participation. For example, people engaged in a *reading context* can be actors, speakers, writers, readers, listeners, or viewers, in either passive or active roles. Roth (2003) describes how scientists constructing their own graphs do not follow strict technical procedures, and their interpretations might be influenced by subjective aspects, for example, they seem to see in the graphs what they are looking for in their research projects.

Although several studies acknowledge these different kinds of contexts and the important role which readers play in the process of interpretation, it seems that Playfair's initial perspective is still very common. The supposition that graphs make the reading of data easier and clearer is commonly held, as well as the view that graphs empower presentations and impress audiences. These beliefs result from the idea that graphs themselves can communicate data. Therefore, there are many concerns raised authors who point to the abuses of graphing in media publications and defend the use of 'perfect' graphs.

3. Reflecting on conceptualizations of interpretation of graphs

The term ‘graph’ can have different meanings in Mathematics, Statistics, Education and other fields, depending on the purpose, the perspective and the situation in which it is applied (WAINER, 1992). In this article, we would like to focus on statistical graphs which in general are comprised of common structural components such as: framework, specifiers, and labels (FRIEL et al., 2001). Figure 1 (below) shows a graph framework in which specifiers are plotted as values along the **y** axis (average of birth numbers), and are paired with values along the **x** axis (years). The specifiers, also called content (KOSSLYN, 1994), are visual dimensions used to represent data values. They might be the lines, bars, point symbols, or other features that specify particular relations among the elements represented by the framework.

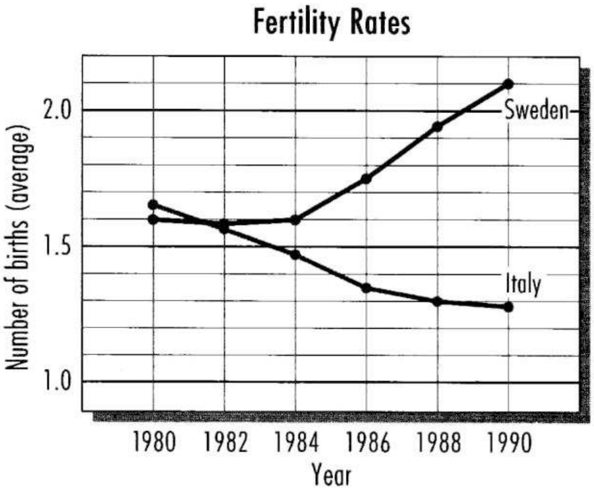

Figure 1: *Social policy and recent fertility changes in Sweden* by J. M. Hoem, *Population and Development Review*, December 1990, cited in *The Economist*, 13 April 1991, p.47 (reprinted from KOSSLYN, 1994).

Kosslyn describes a label as another graphical component. For example, in Figure 1 the axes of the framework bears a label naming a dependent variable [the type of measurement being made – e.g. “Number of births (average)”] or an independent variable (the entity to which the measurement applies – e.g. Year). Other labels indicate values along the measurement scale (e.g.

specific number of births – 1.0, 1.5, 2.0), and the particular units that were measured (the years 1980, 1982, 1984…).

Kosslyn emphasises that this breakdown of a graph into components might help investigations related to graphs because it specifies the purpose of each element. On the other hand, this approach seems to be restrictive because graphs are more than the sum of their parts. In addition, the classifications of the elements of graphs produced by different authors (e.g. FRIEL et al., 2001; JONES, 2000; KOSSLYN, 1994) emphasise the "apparent" components displayed on the graph. However, the consideration of "latent" components is also fundamental for the analysis of graphical structure. For example, Figure 1 (above) describes specifiers or contents which include different variables (fertility rate, country, and years). However, there are other aspects which are not explicit, such as: the choice of Sweden and Italy as examples, and the chosen years. There are also other specifiers which are not displayed in Figure 1 which might be important in making sense of the data presented. For example, specific information about this content might play a fundamental role: the concept of fertility used, the gender, and age of people who composed the sample.

Some authors emphasise that presentation of data by statistical graphs must follow certain technical requirements, such as the use of the basic graphical components and the proportional relationship between the numerical values and their representation. For instance, Tufte (2001) is an author concerned with visual display and design. He argues that the violations of the technical principles by poor designers constitute one form of misrepresentation which can be measured by a *lie factor*, which is calculated by dividing the size of effect shown in the graphic by the size of effect in the data.

Jones (2000) writes for a public involved in business fields which need to use and interpret graphs. He believes that graphs are not simply neutral vehicles of communication. According to Jones graphing is a type of data reduction whereby the complex world impinging on readers' senses can made simpler, and thus easier to understand. Jones emphasises that this data reduction is not necessarily a bad procedure but it has to be done carefully.

The ‘reduction’ of data might be related to factors which precede the production of graphs. An instance comes from Haack (1979) who is a statistical researcher concerned with graphical data presentation. He exemplifies the use of variables such as age and educational achievements which are statistically approached as continuous sets of data. According to Haack, age is frequently recorded to the last birthday or discretely (0, 1, 2, etc), but the exact age of two people can vary by smallest amount of time. On the other hand educational achievement is crudely measured by years of school completed although education is a continuous process. Therefore, the numerical data which express these two indicators are a reduced picture of the ‘reality’. The further manipulation which might be done when this data is displayed graphically might ‘reduce’ the data in other terms.

Authors who discuss the interpretation of graphs (HAACK, 1979; JONES, 2000; TUFTE, 2001) introduce interesting ideas about the interpretation of graphs such as those which we find in print media. However they do not present empirical evidence based on research studies. These commentaries also seem to attribute an excessive power to graphical representation minimising the role of the reader. These authors argue that graphs can be misleading or be used to mislead. However, they seem to believe that it is possible to produce perfect graphs which achieve certain appropriate ranges of technical norms to guide the reader. For example, Tufte (2001) established the notion of “graphical excellence” as a well-designed presentation of data which requires telling the truth about the data to the viewer with clarity, precision, and efficiency. This perspective attributes ‘epistemic fidelity’ (MEIRA, 1998) approaching graphs as ‘inherent mathematical objects’ (ROTH, 2003).

Arcavi (2003) gives an alternative perspective about displaying data that emphasises both components and processes related to the display of data. He introduces a concept of visualisation which is not only related to the graph itself:

> Visualisation is the ability, the process and the product of creation, interpretation, use of and reflection upon pictures, images, diagrams, in our minds, on paper or with technological tools, with the purpose of depicting and communicating information, thinking about developing previously unknown ideas and advancing understandings (p.217).

Arcavi criticises an almost commonplace statement that we live in a world where information is transmitted mostly in visual wrappings, and technologies support and encourage communication which is essentially visual. He emphasises that the complexity of the phenomenon of visualisation is not only related to what comes “within sight”, but we are also encouraged and aspire to see what we are unable to see.

We recognise that it is important to consider claims about the misleading displays of data which media graphs might. However, the complete absence of errors or “graphical excellence” (TUFTE, 2001) cannot be a guarantee of “successful” interpretation. The consideration of the complex range of components and processes (e.g. ARCAVI, 2003) involved in the displaying and interpretation of graphs emphasise the importance and role of the reader as well as the graph.

The complexity of the interaction between a graph and those who use it has been the focus of several research studies. For example, diSessa et al. (1991) emphasise that the understanding of the interpretations of graphs in *school contexts* should be based on what is ‘proposed’ by the teacher, ‘perceived’ by pupils, and ‘negotiated’ by the class group.

Lajoie et al. (1995) discuss studies which approach statistics and mathematics teaching and learning in an ‘active away’. These authors highlight the fact that active approaches which treat statistics as an ill-structured discipline, where there is more than one right answer, can open the doors to alternative forms of teaching and learning that emphasise the constructive, ‘active’ nature of learning involving opportunities to enquire, investigate, analyse, and interpret rather than to compute and memorize.

Pratt (1995) uses the term *active graphing* for a particular pedagogical approach which is explicitly designed to engage children in the use of graphs as a basis for making decisions in an ongoing experiment. The *active graphing* approach emphasises that the process of learning and teaching graphing involves several factors such as children’s everyday informal intuitions and the tools and resources available (AINLEY et al., 2001).

4. Some implications for the teaching and learning of interpretation of graphs

The introduction of the interpretation of graphs as a topic from the early years of schooling is important. However, it is necessary to question the aim of teaching this specific school topic. The answer might be that teaching about the interpretation of graphs can facilitate students' adaptation to the demands of the 'information era'. Therefore pupils need to learn how and when to decode data displayed on graphs. However, pedagogic emphasis is often more on the technical skills of drawing graphs than on interpretation.

The answer given by curriculum makers from different countries emphasises that the teaching of graphing in primary schools should introduce and develop the kinds of knowledge which enable students to be critical citizens when interpreting graphs in daily situations. Generally, the official documents advise that teachers need to teach pupils beyond the level of knowing how to make simple readings of graphical representations. Therefore, students need to be able to describe and interpret their real world experiences using mathematical and statistical knowledge (e.g. BRASIL, 1997).

The prescriptions from curriculum makers emphasise problem solving as an important dimension of teaching about the interpretation of graphs in the early years of school. However, analysing in detail some of these documents we can see that their suggestions for pedagogical activities are not coherent with these aims because they would not engage the pupils in problem solving situations (AINLEY; MONTEIRO, 2008). The reality in most classroom settings is still associated with conventional school contexts in which the teaching of graphing emphasises several sub-skills by a succession of tasks, such as scaling, drawing axes and plotting points (AINLEY, 1995, 2000).

One suggested innovation in the teaching of graphing is the development of pedagogical activities which make use of graphs from media publications, such as: magazines, newspapers and books. For example, Watson (1997) suggests that misleading media graphs can be an ideal vehicle to provide initial motivation for the study of the interpretation of graphs as well providing the basis for assessment of stages of learning about this topic. However, the use of graphs taken from *reading contexts* in activities associated with the *school contexts* needs further analysis. Firstly, it seems that 'motivation' alone is not a sufficient justification to introduce the use of media graphs in classroom activities. Ainley (2000) emphasised that the novelty of a pedagogical situation might initially cause enjoyment and attract children's attention, however purposeful engagement must be the basis for the development of pedagogical tasks.

Secondly, Adler (2000) emphasises that the use of *out-of-school resources* in and for *school* mathematics involves a process of recontextualisation (BERNSTEIN, 1996) which is complicated and sometimes contradictory. Therefore, the importation of media graphs to *school contexts* needs to consider elements which are associated with their production and use in *reading* contexts.

Finally, the deliberate use of 'misleading' media graphs provides the opportunity for a specific type of interpretation. However, misleading aspects are not always visible and even accurate graphs can be open to different interpretations in specific contexts.

Whilst we might argue that ideally in *school contexts* the processes of teaching and learning about graphs makes reference to both mathematical elements from *enquiry contexts* and understanding of data in *reading contexts,* we also recognise that *school contexts* have distinctive characteristics which set them apart. In *school* contexts, the teacher's purpose is for her pupils to learn about particular mathematical ideas, and so her attention will be on asking questions and setting tasks which emphasise mathematical knowledge, but which largely ignore the contextual knowledge which is a key feature of *reading* and *enquiry* contexts. The way in which such questions focus the attention of learners may generate very different perspectives on the graph being used. For example, pedagogic questions about the graph shown in Figure 1 might include: what was the number of births in Italy in 1986? What was the difference between the numbers of births in Italy and in Sweden in 1990? These questions will require the use of mathematical knowledge in reading data from the graph, and making calculations, but overlook any issues concerning the interpretation of the numbers given as answers, such as what 1.35 births might mean.

The interfaces between *school contexts* and *enquiry* and *reading contexts* seem very complex and an important challenge to mathematics and statistics education.

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