® ENHANCING EFFECTIVE COMMUNICATION OF STATISTICAL ANALYSIS TO NON-STATISTICAL AUDIENCES

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This paper explores the potential of enhancing effective communication of information arising from statistical analyses to a non-statistical audience using various graphical forms. In this regard we can learn a lot from the business world where often senior management don't have the time to wade through complex summary tables of statistical analyses. It is far more efficient to use good graphic displays in order to communicate the essential ideas. Modern computer software packages offer a goldmine of opportunities to present statistical information to non-statistical audiences. As communicators we need to provide appropriate experiences within the structure of our teaching and/or consulting programs. The importance of context in understanding graphical output is discussed as well as examples of a few of the many and various graphical options available in several commonly used software packages.

INTRODUCTION

Modern computer software enables the user to engage in statistical analysis with relative ease. Calculations once done manually are now done by the software in a matter of seconds with no computational errors. Researchers are now able to analyse much larger sets of data and to perform highly sophisticated analyses. The efficiencies associated with data handling and computation have been more than matched by the advances in the graphical capabilities of modern software. Layered plots, rotatable 3-D plots and surface plots and even four-dimensional plots allow us to look more deeply than ever before into the structure of the data available for analysis. However, there are traps for the unwary, or inexperienced, and the communication of the resulting information requires careful thought and consideration, particularly for non-statistical audiences.

Computers don't *"decide"* whether or not underlying assumptions are required or have been satisfied. Neither do computers *"know"* if the data are qualitative or quantitative, nor even if a selected analysis is appropriate. Most educators in statistics have ample cases of examples of statistical misuse.

To effectively communicate statistical information using graphical means an audience has to be identified. Each audience may possibly have a different frame of reference, or access to different work-related contexts, all of which need to be ascertained before graphical forms can be used to communicate and enhance appropriate statistical understanding. Passion, creativity, lateral thinking and an ability to empathise with the client are useful characteristics of educators, or anyone else for that matter, wanting to effectively communicate statistical information to a non-statistical audience.

In my experience the non-statistical audiences I have been required to communicate with may be classified into three broad categories:

1. Undergraduate Students (arising out of my teaching program)
2. Industry Personnel (arising out of consultancies)
3. Professional Public (arising out of program evaluation and writing of official reports)

Each group may be characterised by sets of different forces interacting to affect the degree to which various statistical concepts might be understood or interpreted. Figure 1 is a schematic representation of the underlying forces identified from interviews with small samples selected from each of the three groups described above.

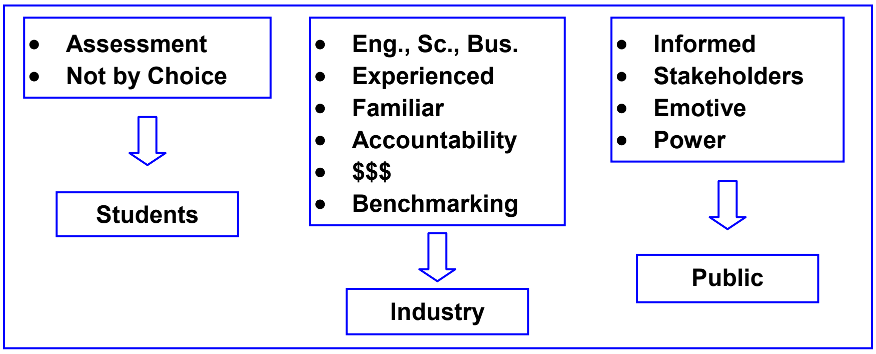

Figure 1. Outline of characteristics pertaining to three non-statistical audiences.

By way of example, whilst industry personnel are certainly interested in averages (targets) they are often more concerned with variation (or consistency) with respect to those targets. These people regard statistics as a necessary analytical tool. The Professional Public on the other hand tend to be more interested in the final result/outcome/number, where magnitude is a point of focus rather than the details of "the journey". Variation is usually not an issue, apart from maximums and minimums where appropriate. Statistics is seen as a necessary evil and best left to those bent that way – just give us the numbers! Undergraduate students of statistics, especially at introductory levels, are primarily concerned with passing the unit. Whilst most students see some relevance in statistics with respect to their chosen area of study, the subject is typically not one they would study by choice. Only a small proportion choose to continue past the introductory level and into some of the more specialised statistical units such as experimental design, time series analysis and multi-variate procedures. They see statistics as a hurdle requirement made more complex by the *foreign language* perception of the subject with it's α-levels, p-values, H_0's, Type I errors, and so on. Hence the graphs constructed and used by each of these groups is governed by their needs which are controlled by different forces, i.e. they are context dependent.

LITERATURE REVIEW

Roth and Bowen (2001) showed graphing to be a skill dependent upon context. With respect to scientists in particular they found that interpretation of graphs was highly contextual and dependent upon familiarity with the subject matter pertaining to the graph. Previous studies by Roth (1998) showed that if scientists are unfamiliar with a particular graph they often "do not arrive at the collectively accepted standard interpretation". The meaningfulness of graphs arises out of the extent to which the aspects or features of the graph (signs) are an integral part of some particular context (practical activities of those interpreting the graph). For those who do not operate within the context then interpretation of the graph is limited. This study was based upon line-graphs and related to interpretations from such graphs of points of intersection, increasing or decreasing rates, local maxima/minima, etc.

Makar and Confrey (2002) argue that a compelling context leads to improved classroom practice when teachers are immersed in content beyond their curriculum. Their study investigated the reasoning required to investigate two groups and in so doing they divided the required concepts into four constructs comprising measurable conjectures, tolerance for variability, understanding of context, and the ability to draw conclusions and/or inferences based on data. They quoted an example from their study that required teachers to compare several pairs of graphs. The importance of context was highlighted by the teachers who demonstrated a deeper and richer understanding of the data evidenced by prolonged discussion and recognition of the relevance of variation, all of which was absent when the graphs were compared without a context.

Wild and Pfannkuch (1998) also consider context to be a critical factor in statistical thinking and Friel et al. (2001) in specifically addressing graph comprehension describe students' abilities to not only read the data, but to also read between the data and to read beyond the data. Makar and Confrey (2002) found that teachers generally chose to use the familiar descriptive statistics to support their hypotheses rather than the more powerful tools of statistical inference.

Intuition was preferred when determining whether or not the observed differences were large enough to be considered significant.

Martin (2003), (not this author) claims that students respond well to interesting and humorous stories, and presents a case for using analogies as a useful teaching tool to enhance statistical memorability. He states that analogical thinking is a cognitive tool that uses existing knowledge of familiar scenarios as a basis for understanding new or novel situations. Martin provides several interesting examples of using analogies to enhance students' understanding of histograms and boxplots. In each case the analogy used is aimed at assisting students in coming to terms with particular constructional elements of the graph. I am suggesting that such graphs can bridge the communication gap between the data and an understanding of the important underlying statistical concepts within the data in much the same way. This should be particularly so if the usual "issues" associated with the construction of appropriate graphs are removed.

Effective communication of statistical information has been enhanced by the graphical capabilities of modern computer software packages. Turville and Giri (2001) suggest that computer generated graphs offer several advantages in that minimal computational effort is required, the graphs are produced quickly and exploration of a variety of potentially useable graphs is more likely to occur as a result. They draw attention to the pitfalls of using the default settings of some software, and to the temptation to make use of features such as shadows, 3-D effects, etc. They suggest that well designed graphing activities can incorporate the processes required for good statistical analysis.

Yu and Stockford (2003) focused upon the mental and behavioural processes of users (with advanced statistical knowledge) during graph interpretation. Data-driven graphs (related to research) are distinguished from function-driven plots (applied to teaching and presentations). The distinction between spatial-oriented and temporal-oriented displays is also considered. The packages used in this study included S-Plus, SAS, SyStat and Maple. The efficacy of various high-dimensional data visualisation techniques is explored in relation to the cognitive limitations of human perception due to the multi-dimensionality of multivariate data. Whilst advances in computer technology have given us access to rotatable 3-D plots the simultaneous viewing of more than three variables is still a challenge. Yu and Stockford were able to confirm their belief that visualisation tools require an exploratory attitude and found that the degree of user exploration is strongly tied to the accessibility of the features provided in the software.

METHODOLOGY

A pilot study was undertaken with respect to the three groups defined above. The purpose was to gain understanding of each group's background knowledge of, and familiarity with, current graphical forms used to represent data or statistical information. The graphical forms used were those commonly found in tertiary statistics courses used for categorical and quantitative data, as well as those used to explore relationships between at least two variables. The graph forms included bar graphs, pie charts, histograms, box plots, stem and leaf displays, scatter plots, line graphs, and 3-D plots.

Informal discussions were held with individuals selected from each of the defined groups. These were convenience samples because of my limited experiences with respect to the first two groups in particular. Interviewees from the Public group (12) included primary school teachers and health professionals, whilst those from the Industry group (15) included personnel from several manufacturing and food companies. The undergraduate students (40) were primarily selected from psychology and the applied sciences. In each case the discussions were aimed at determining the prevalence, preference, familiarity, comfort, etc with respect to producing or interpreting various graphical displays. Participants were each asked whether or not they could obtain the graphs from EXCEL, or some other software, whether they had personally constructed the graphs (used) , and to rate how often they constructed (usage) the graphs on a scale ranging from 0 (not used) to 10 (used all the time).

DISCUSSION

Each of the students had completed or almost completed an introductory statistics course in which they were expected to make use of Minitab, SPSS and EXCEL to analyse data. Hence,

Figure 2 shows that their ability to obtain all of the graphs except 3-D plots was very high (80%+). This was particularly so for bar graphs, pie charts, histograms, and box plots (100%). The proportions of Students who had actually constructed the graphs followed a similar pattern, except only 60% claimed they had constructed stem and leaf plots and line graphs. Due to the objectives and structure of the statistics unit in which they were enrolled this is not surprising. Usage scores for bar graphs, pie charts, histograms, and box plots were also very high (average score > 7) with scatter plots, stem and leaf plots and line graphs scoring moderately (average scores between 3 and 6). The average usage score for 3-D graphs was very low. There was no difference in usage scores between graphs used to display categorical data, whereas for quantitative data histograms had higher usage scores than box plots and both of these graphs scored considerably higher than stem and leaf plots. For graphs used to display relationships, scatterplots had higher usage scores than line graphs.

The patterns for the Industry group (Figure 3) were quite different to those of the students. All of those interviewed (15) could obtain, and had actually constructed bar graphs and pie charts. Most claimed they could obtain a histogram, box plot, scatter plot and a line graph (70%+), but average usage scores for these graphs differed considerably in that line graphs and box plots were used far more often than scatter plots and histograms (6 to 7 compared to 1 to 2). The other graphs rated very lowly. The usage score for box plots was higher than perhaps expected because this graph form had only been introduced in recent quality control training programs associated with the consultancy. Their usefulness was very quickly perceived, specifically in relation to comparisons between groups, or stratifications within groups.

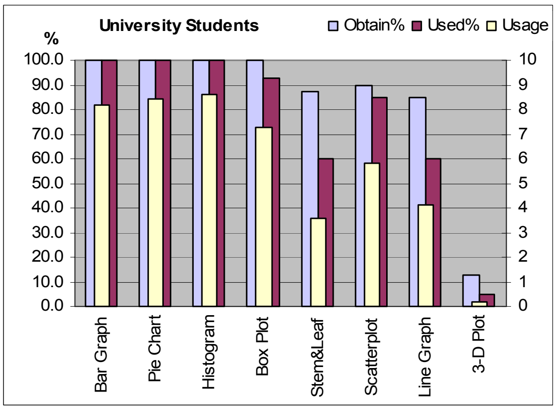

Figure 2. Student graph familiarity and usage.

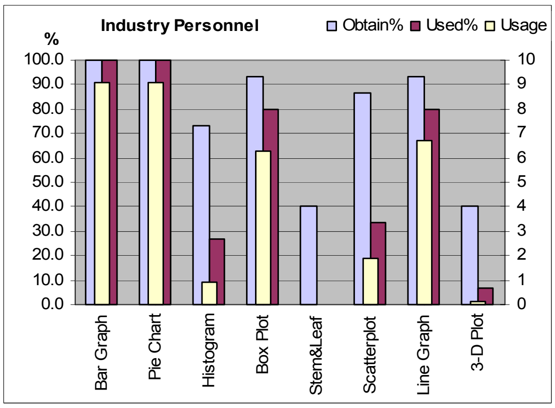

Figure 3. Industry Personnel graph familiarity and usage.

The profile for the Professional Public group (Figure 4) was different again, particularly with respect to obtaining the graph forms involved. All of those interviewed in this group (12) had constructed bar graphs and pie charts and a majority had constructed line graphs (75%). Most of those interviewed (>70%) could obtain bar graphs and pie charts and less than half (30–40%) could obtain scatter plots and line graphs. The average usage scores for bar graphs, pie charts were moderately high (6 to 7) with some usage of line graphs (3.9). Histograms, box plots, stem and leaf plots and 3-D plots were absent in all aspects. Typical comments from those interviewed in this group included

"I suppose EXCEL could do the job. "
"I don't know how to get these graphs; I usually ask someone to show me, or to do it for me."
"Others are paid to do this sort of thing."

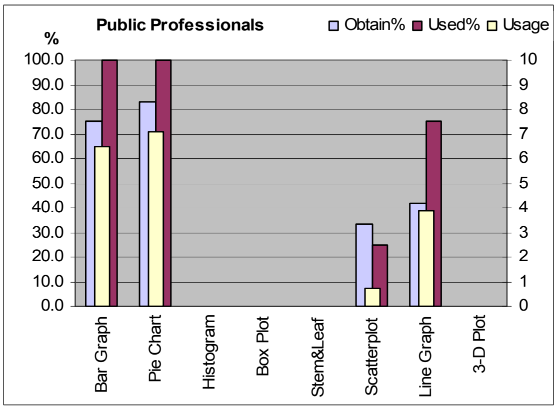

Figure 4. Public Professionals graph familiarity and usage.

With respect to the stem-and-leaf graph form, all of those interviewed from the Industry group had been exposed to this graph in the training program delivered to them. Whilst the majority of students could obtain and construct a stem-and-leaf graph, they were not seen as particularly useful. When questioned on this the consensus view was that there were too many numbers and that it was all too confusing.

In summary bar graphs and pie charts rate highest overall, followed by boxplots, line graphs and scatter plots to varying degrees for each group with respect to the three aspects considered. Histograms and stem and leaf plots only featured strongly for the student group. The 3-D plots remain relatively unexplored in all groups.

Whilst this information may be useful in understanding the nature of what makes for effective communication of statistical information using graphical means, effective communication requires more than a familiar graph or one that is easy to understand. Various researchers have presented strong cases for the importance of context in interpreting graphical information (Makar & Confrey, 2002; Wild & Pfannkuch, 1998; Roth & Bowen, 2001). The issue of context, I believe, is more of a concern with students than it has been with clients from both Industry and Public organisations. Clients from these groups are typically well embedded in work related contexts. So much so that on one occasion when presented with a time-series of boxplots (a graphical form previously unknown to the client) an exclamation of “Ah-ha! That’s our start-up problem” was immediately forthcoming. A similar experience was had with another client who was concerned about excessive variation in a cheese making process. Again, a time-series of boxplots showed that the problem was specifically associated with one part of the process. In both cases breakthrough was achieved by inverting the data matrix; whilst not an unusual procedure in itself it was something nobody had previously used. Both of these cases illustrate an interesting difference in client focus. The focus of the client in one instance was the behaviour of the process average, whilst in the second case the client was particularly interested in the changing variation over time. The advantage of boxplots is that they do allow for easy comparisons to be made with respect to both centre and spread.

In a consultancy involving the evaluation of an educational health and safety program line graphs were used to demonstrate the differences and problems associated with using raw counts of instances rather than using rates of occurrence. Similarly line graphs were used to demonstrate the basis upon which various cost benefit analyses were completed. Comments made by relevant members of the group after a recent presentation led me to conclude that the combination of familiarity with the graph and the context within which it was being used enhanced effective communication of what had been reported in the evaluation.

Students however, do not have the same type of work related environment within which to frame a context. As educators it is our job to *manufacture* such contexts that have at least some meaning for the students. Hence the recent growth and development of statistics education with research into activity-based learning, ownership of data, meaningful data sets, problem solving activities, etc. Several years ago we introduced activities and simulations into our first-year statistics courses (Martin, Roberts, & Pierce 1994). The aim of one of the computer simulations was to demonstrate various aspects of the central limit theorem. At the time it was thought to be innovative, creative and worth reporting. Today I am not convinced that it provided as much assistance as we thought to students grappling with the concepts underlying the central limit theorem. Whilst the simulations certainly represented an improvement on the theoretical approach involving symbolic representation, I believe we can be more effective by providing a more meaningful context for the students, one that is experientially real for them. Many of our colleagues thought the simulation was an excellent idea, but they have a different and more meaningful context or frame of reference within which to make the link between the concept and what they see.

Recent developments in computer software have also taken the concept of using familiar graphs as an effective means of communicating complex statistical ideas to audiences of varying backgrounds. An excellent example of this is the graphical output from Minitab associated with a measurement systems analysis known as a Gauge R&R study in quality control circles. This analysis takes the relatively complicated output resulting from an experimental design known as a random effects model and turns it into graphical output consisting of bar graphs and line graphs. Other examples of communicating complex statistical ideas using familiar graphical forms include normality tests and measurements of effect size from various experimental designs. The graphical forms used include combinations of scatter plots, line graphs and bar graphs.

CONCLUSION

Familiarity with, and exposure to various graphical forms, whether in professional journals, formal reports, research, university course requirements or mass media output, forms the basis of a frame of reference or context around which effective communication of statistical ideas and concepts may occur.

The challenge is to use common graphical forms to illustrate or demonstrate some physical state, or concept, or abstraction. To do this effectively requires creativeness on the part of the communicator and a meaningful context for the receiver. For as Roth (1998) showed even highly trained professionals often fail to agree on the correct interpretation of graphs based upon an unfamiliar context. Others also have presented strong cases for the importance of context in interpreting graphical information (Makar & Confrey, 2002; Wild & Pfannkuch, 1998; Roth & Bowen, 2001).

This pilot study shows that for three broad groups of potential audiences there is strong affinity with bar graphs, pie graphs, line graphs, and potentially, with boxplots. This suggests that effective communication of statistical information might be enhanced by using these graph forms whenever applicable. Evidence from recent software developments in graphics seems to support this, particularly in relation to the use of bar graphs and line graphs.

And finally, there is a need for some degree of creativity and lateral thinking on the part of the individual who wants to make the communication connection. The resulting graph may not be all that complex. Rather, it may simply be a different way of looking at some situation, or that a meaningful link has been made between graph form and statistical concept. Very often I have heard clients say *"I wonder why nobody thought of that before?"*

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