Observations on the Type and Quality of Graphs Used in the ASA/NCTM Annual Poster Competition during the Years 2013 to 2016

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Abstract
Each year, the ASA/NCTM Joint Committee on the Curriculum in Statistics and Probability and the ASA Education Department encourage students and their advisors to participate in its annual Poster Competition and Project Competition. Despite many high quality posters, there are frequently posters with relatively weak graphs among the winners. This was observed by members of the Statistical Graphics section and a task force was formed in late 2012 to collaborate with the ASA/NCTM Joint Committee to further improve the graphs in the posters. In this article, we will summarize which types of graphs have been used most frequently in the winning posters from 2013 to 2016 and which frequent mistakes could be found in these posters during these four years. We will discuss the single most frequent type of mistake, that is, several variations of 3D graphs, in more detail.

Key Words: ASA Statistics Poster Competition; Winners; Effective Graphs; Misleading Graphs; Deceptive Graphs

1. Introduction

The *American Statistical Association* (ASA) runs an annual *Poster Competition and Project Competition* (`http://www.amstat.org/asa/education/ASA-Statistics-Poster-Competition-for-Grades-K-12.aspx` and `http://www.amstat.org/asa/education/ASA-Statistics-Project-Competition-for-Grades-7-12.aspx`) under the direction of the *ASA/National Council of Teachers of Mathematics (NCTM) Joint Committee*. The *Project Competition* was initiated in 1987. The *Poster Competition* was initiated by Lorraine Denby of the *ASA Section on Statistical Graphics* in 1989 and it was first held in the spring of 1990 with Jerry Moreno as chair (see `http://www.amstat.org/asa/files/pdfs/EDU-History.pdf` for further details). Over time, the *ASA Section on Statistical Graphics* became less involved in the ASA *Poster Competition* and its members almost completely forgot about it. Around 2010, some members of the *ASA Section on Statistical Graphics* started to notice "bad" graphs among the winners of the ASA *Poster Competition*.

In response, the *ASA Section on Statistical Graphics* formed a special task force in the fall of 2012 (the three authors of this article with Symanzik as its chair) to review graphical content and, in close collaboration with the *ASA/NCTM Joint Committee on the Curriculum in Statistics and Probability*, make recommendations on the structure of the *Poster Competition* and criteria for judging the graphs. Our initial observations related to the winners of the 2013 ASA *Poster Competition* were reported in Symanzik et al. (2014), followed by Heiberger et al. (2014).

In this article, we extend our observations to the winners of the 2013 to 2016 ASA *Poster Competitions*, i.e., to four years of data with 57 winning posters and a total of 234 graphs. In Section 2, we provide an overview on the most frequently used graph types in the winning posters and we report on common problems seen in the graphs. Special

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attention will be given to the single most frequent type of mistake, i.e., several variations of 3D graphs. In Section 3, we try to provide some explanations why so many winning posters contain suboptimal graphs. We outline the future plans of our task force in Section 4. We finish with an overview of sources for constructing better graphs in Section 5 and a short discussion in Section 6.

2. Frequently Used Graph Types and Common Problems Seen in Graphs

The ASA *Poster Competition* breaks down the submissions into four age groups: Kindergarten to Grade 3, Grades 4–6, Grades 7–9, and Grades 10–12. Typically, three winners were awarded each year in each age group, resulting in a minimum of 12 winning posters in a specific year (as in 2014 and 2016). Sometimes, there were additional posters that deserved honorable mention and posters that were tied in first, second, or third place in a grade. Therefore, the number of winning poster was 17 in 2013 and 16 in 2015. Our analysis is based on photographs of the actual winning posters that were provided to us by the American Statistical Association. The graphs reprinted in this article have been extracted from these photographs. We apologize in advance for any details we may have overlooked or misinterpreted in these photographs due to their relatively low resolution, compared to a much higher resolution of the actual posters.

The total number of graphs used in the winning posters varied considerably during the four years: 76 in 2013, 44 in 2014, 63 in 2015, and 51 in 2016. The average number of graphs per poster was around 4, ranging from 3.7 in 2014 to 4.5 in 2013. However, in many posters, the same graph types have been used more than once. As an extreme, one poster in 2016 had a total of eleven graphs, the largest number of graphs in a single poster during these four years. But, seven of these graphs were pie charts and four were grouped bar charts. Thus, there were only two unique graph types in this poster. Therefore, it makes more sense to consider only unique graph types used in the winning posters: 41 in 2013, 25 in 2014, 35 in 2015, and 28 in 2016. Only one poster in 2013 used five unique graph types. All other posters had four or fewer unique graph types. The average number of unique graph types per poster was slightly more than 2, ranging from 2.1 in 2014 to 2.4 in 2013. When a particular problem occurred in a graph in a poster, this problem typically also occurred in all other graphs of the same type in that poster. Therefore, the variable *UniqueGraphs* is our reference variable when it comes to suboptimal graphs in a poster.

Figure 1 provides an overview of the type of graphs used in each year. By far the

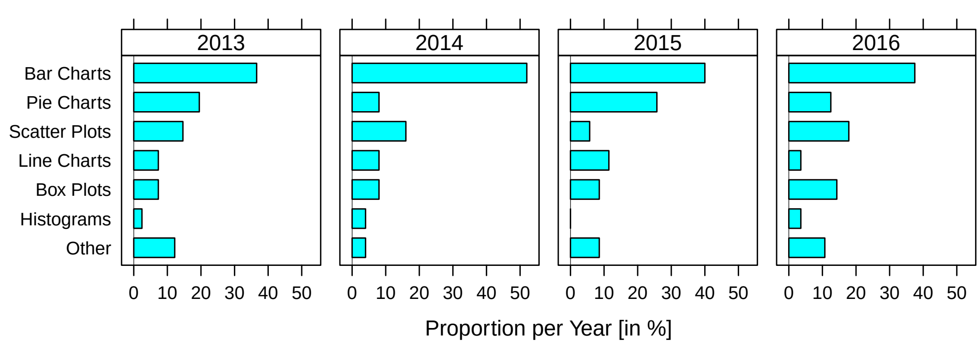

Figure 1: Bar chart showing the percentage of the main graph types for the years 2013 to 2016.

most frequently used graph type in each year are bar charts, such as ordinary bar charts, grouped bar charts, stacked bar charts, and different versions of 3D bar charts. They make up from 37% (in 2013) to 52% (in 2014) of the unique graphs per poster. The second most frequently used graph type are pie charts in 2013 and 2015 (20% and 26%, respectively) and scatter plots in 2014 and 2016 (16% and 18%, respectively). Pie charts contain two–dimensional (2D) pie charts, 3D pie charts, and exploded 3D pie charts. Scatter plots contain regular scatter plots and scatter plots enhanced with fitted lines and confidence intervals. No other of the three other main types of graphs (box plots, histograms, and line charts) makes up more than 20% of the *UniqueGraphsPerPoster* in any of the four years. “Other” graphs contain rare occurrences of dot plots, maps, and graphs related to the normal distribution and make up at most 12% (in 2013) in any of the four years.

2.1 Observed Problems in the Winning Posters

We observed the following 27 major problems in the graphs in the four years. All of the following make a graph suboptimal in our opinion. The numbers in square brackets indicate how many of the unique graphs had that particular problem. One example of each of these problems is shown on the left side of a figure while one or more possible improvements are shown on the right side of the same figure.

Bar Charts: Pseudo three–dimensional (abbreviated as 3D in the text) bar charts [7 – see Figure 2 for example]; bar charts with no spaces between the bars [3 – see Figure 3 for example]; bar charts that do not start at zero [2 – see Figure 4 for example]; and side–by–side bar charts that do not have a common scale [1 – see Figure 5 for example].

Pie Charts: Three–dimensional (3D) pie charts [6 – see Figure 6 for example]; and “exploded” pie charts where segments of the pie have been pulled out of the pie chart [3 – see Figure 7 for example].

Line Charts: Charts that use an incorrect scale on the horizontal axis [2 – see Figure 8 for example].

Histograms: Histograms with extra spaces between the bars [2 – see Figure 9 for example].

Other: Bubble charts where the diameter is proportional to the numbers (and not the area) [1 – see Figure 10 for example].

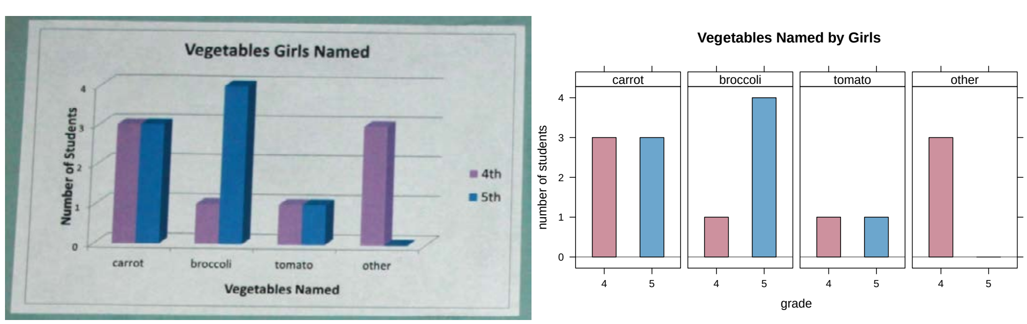

Figure 2: 3D grouped bar chart (left) and improved version as a 2D grouped bar chart (right). By using both top labeling (in the strip label here) and bottom tick mark labeling, we no longer need a legend and the graph becomes simpler to read.

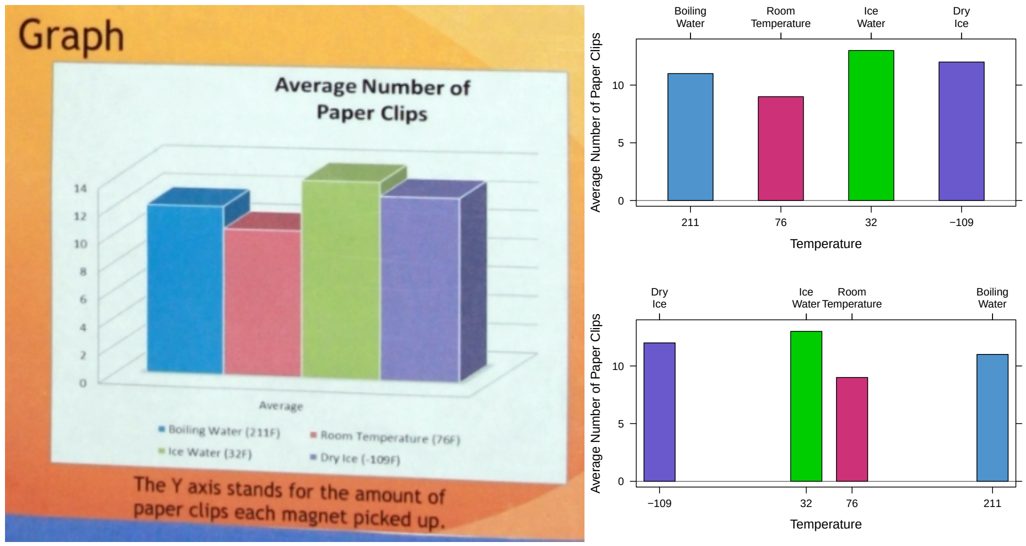

Figure 3: 3D bar chart (left) with no spaces between the groups and a confusing legend. The legend has two rows, thus hiding the systematic decrease in temperature in the bars from left to right. There are two revised versions (right). The top right version uses an ordinary 2D bar chart, with well–spaced bars in the same decreasing order as the original. There are now two sets of horizontal axis labels. The decreasing temperatures are on the bottom axis. The descriptive terms on the top axis are aligned with the bars, hence an independent legend is no longer needed. Although multiple colors are not needed, we retained them to match the original figure. In the bottom right revised bar chart, we show an increasing temperature scale and positioned the bars at horizontal distances proportional to the numerical temperatures.

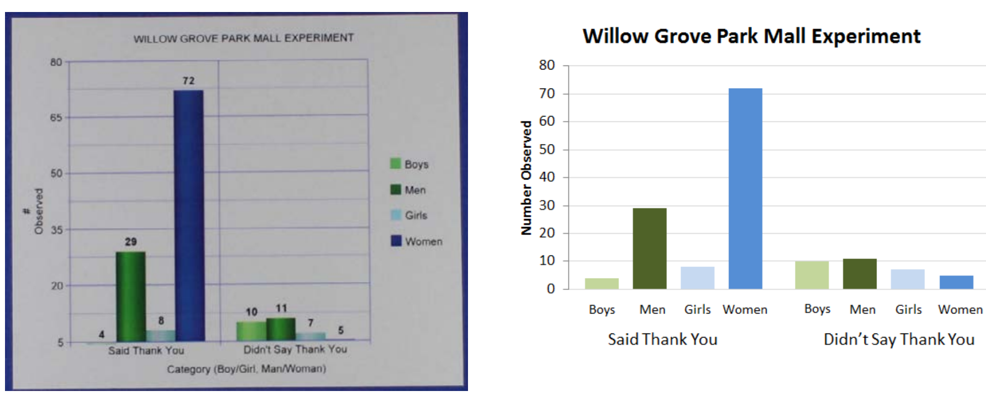

Figure 4: Grouped bar chart that does not contain 0 on the vertical axis (left) and improved version that starts at 0 (right). The use of two levels of x–axis labeling permits us to avoid the use of a legend. In the original version, the horizontally oriented positions were explained by a vertically oriented legend.

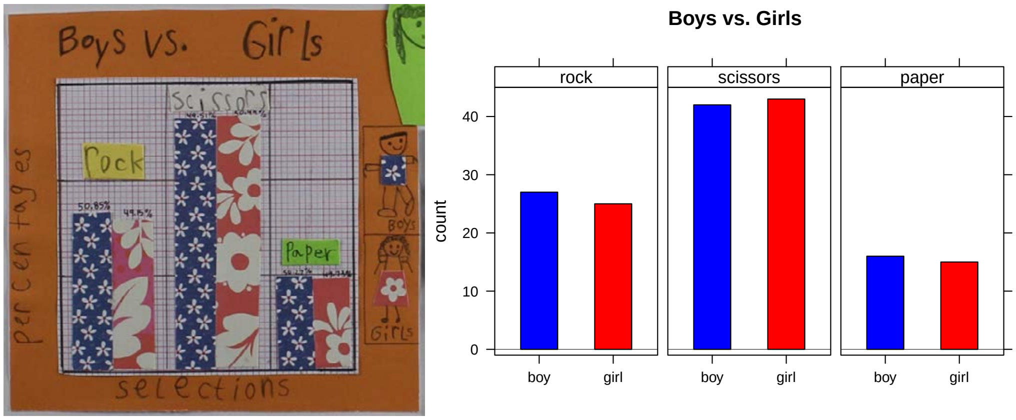

Figure 5: Grouped bar chart that does not have a common scale for the vertical axis (left) and improved version that uses a common scale for all three groups (right). The primary problem in the original graph is that the height of the bars represents counts. But the bars are labeled as percentages. Suddenly, 50.85% (for boys, rock) is represented by a much shorter bar than 49.51% (for boys, scissors). The original figure is missing context. We are assuming that the number of axis intervals represents the underlying count. Our version of the figure is consistent in length of bars and identification on the left axis.

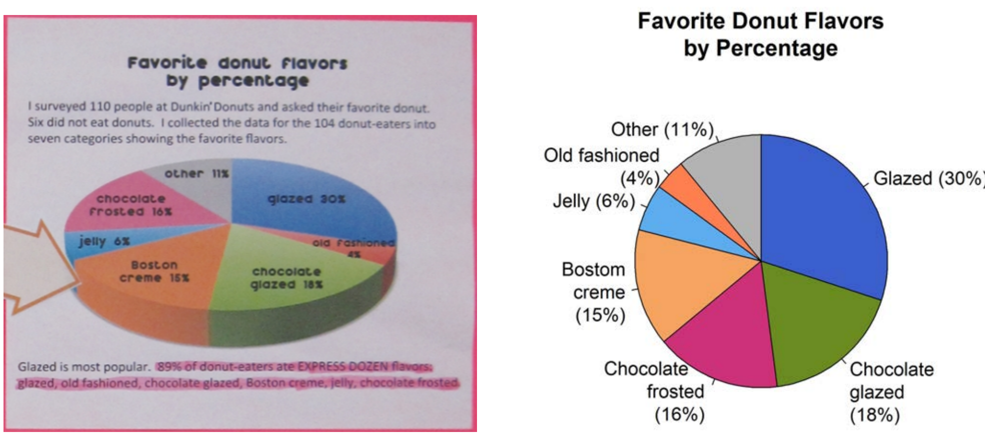

Figure 6: 3D pie chart where the oblique angle distorts the observed percentages from the labeled percentages (left) and improved version as a 2D pie chart (right). Moreover, the original pie chart is not sorted in a meaningful way. This also has been improved by sorting from highest to lowest percentage, but with “Other” sorted at the end. While we tried to match the original colors, a different (less intense) color scheme might be preferable.

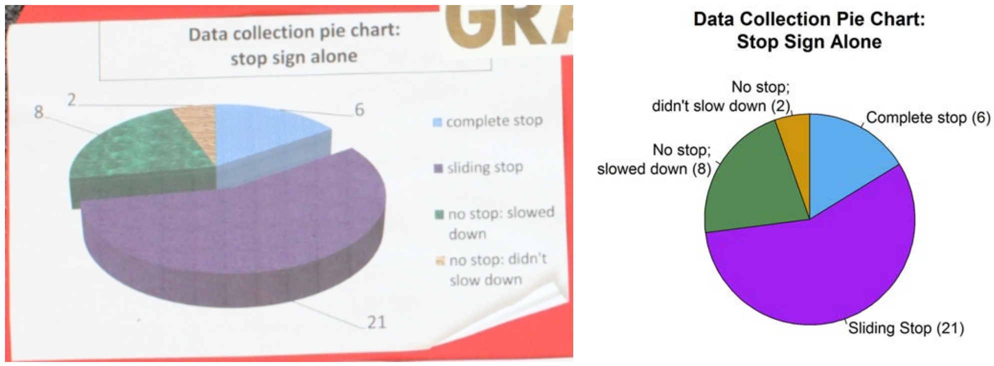

Figure 7: "Exploded" oblique 3D pie chart (left) and improved version as a 2D pie chart (right). We do not understand why the designers of the original graph isolated an intermediate value ("sliding stop") into its own group. To us, the natural grouping is stop ("complete" and "sliding") and no–stop ("slowed down" and "didn't slow down"). While we tried to match the original colors, a different (less intense) color scheme might be preferable.

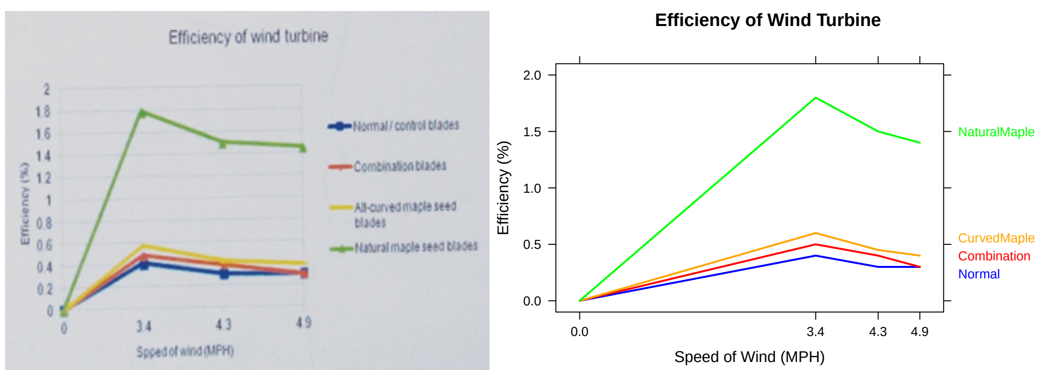

Figure 8: Line chart (left) with (a) incorrectly spaced horizontal axis, (b) confusing legend for the lines and colors, and (c) unaligned decimal points in the left–side tick labels. Our improved version of the line chart (right) has (a) the horizontal axis spacing proportional to the values on the tick labels, (b) right–side axis tick labels aligned with the right–side positions of the curve, and (c) aligned decimal points in the left–side tick labels.

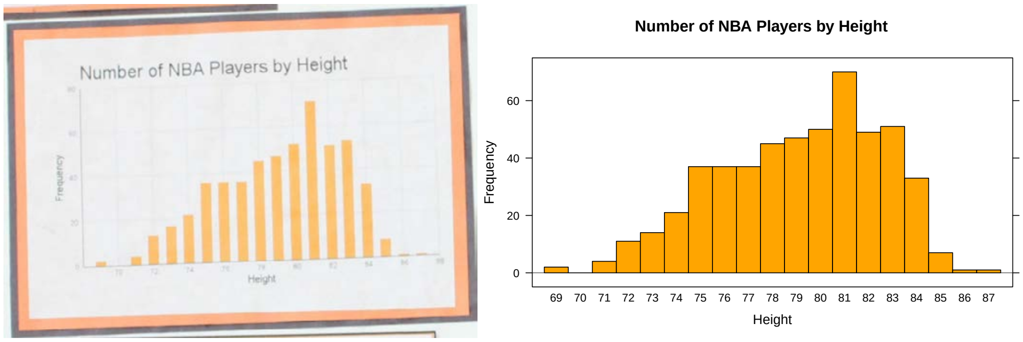

Figure 9: Histogram with spaces between the bars (left) and improved version as a histogram with no spaces between the bars (right). As height is a continuous quantitative variable, we can assume that the actual measurements have been rounded (or truncated) to the nearest inch, but that there are definitely no gaps in the data. Therefore, there shouldn't be any spaces in the histogram. Even for a discrete quantitative variable, one usually wouldn't add spaces between the bars — unless there is really no data in a given interval.

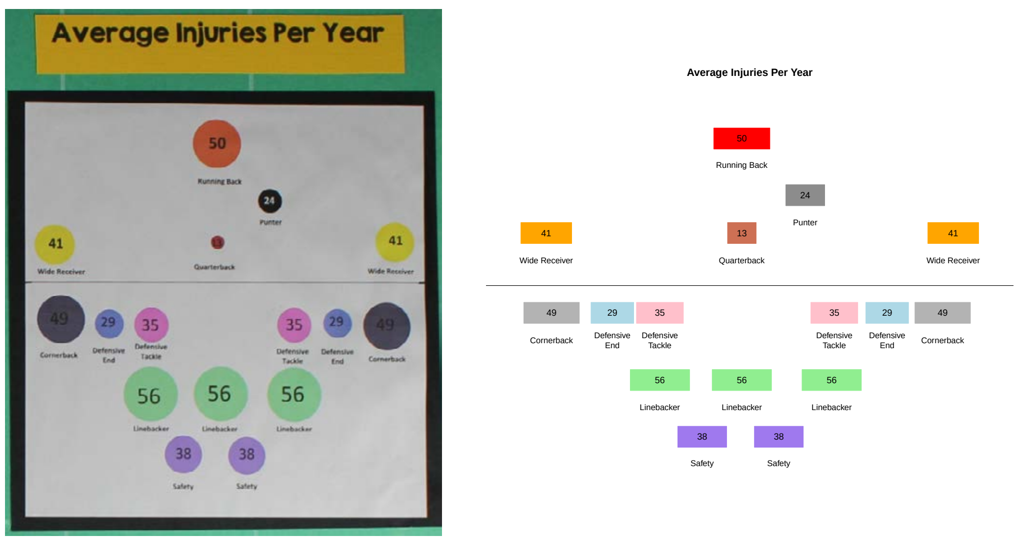

Figure 10: Bubble chart where the values incorrectly determine the diameters of the bubbles, thus exaggerating increases in a quadratic way (left) and improved version of a "bubble" chart where bars, instead of bubbles, are used to encode the values (right). In general, it is difficult to extract precise information from circular areas.

The two most frequent major problems were 3D bar charts and 3D pie charts with almost 50% of all major problems. One poster seemed to inappropriately make use of a pie chart because the data were not part of a whole, but this graph also was a 3D pie chart and did not get assessed separately. No major problems were observed in scatter plots and in box plots. Other minor problems were observed, but did not get tracked down in detail for our analysis. These minor problems included no meaningful sorting of the bars and segments, e.g., in bar charts and pie charts; minor problems with colors, e.g., inconsistent use of color among multiple graphs or colors difficult to distinguish from each other; and minor problems with annotations, e.g., missing axis tick marks or incomplete legends.

As previously mentioned, when a particular poster contained a graph with one of these major problems, in most instances all other graphs of the same graph type on that poster also suffered from the same main problem. Therefore, the variable *UniqueGraphs* is used as our reference variable. Overall, 21% (27 out of 129) of the unique graphs were suboptimal. For the four years, the percentages of suboptimal graphs ranged from 14% (4 out of 28) in 2016 to 26% (9 out of 35) in 2015. Notably, there was not a single 3D chart among the winning posters in 2016!

There was no obvious pattern with respect to suboptimal graphs in the four age groups. In Kindergarten to Grade 3, there were 21% (6 out of 28) suboptimal graphs, in Grades 4–6 29% (10 out of 25), in Grades 7–9 23% (7 out of 30), and in Grades 10–12 11% (4 out of 36). Surprisingly, students from Kindergarten to Grade 3 performed (slightly) better than students from Grades 4–6 and from Grades 7–9.

2.2 Specific Problems with 3D Graphs

As mentioned in the previous section, adding an unnecessary third dimension to bar charts and pie charts was the most common problem we saw in the poster competitions. There are several reasons that we object to these 3D charts. Our main objection is that most people are misled by them. They don't know where the value is encoded. In Figure 11 (left), is the value at the front of the bar as indicated by the arrow on the A bar or is it in the back of the bar as indicated by the arrow on the B bar? Most readers judge the A bar to be around 0.75 and the B bar to be about 1.75.

Figure 11 (right) shows a 2D bar graph of the same data. In this case the values are unambiguous. We see that the value of the A bar is 1 and that of the B bar is 2. Notice that the bars in Figure 11 (left) do not touch the back wall of the graph. The distance from the bar to the back wall is called the gap depth. This is an option that can be changed in Excel but not many users are aware of that. The default gap depth in Excel is not zero. The result is that the bars appear shorter than they should. Both graphs in Figure 11 were drawn using Excel 2010.

Our second objection to pseudo 3D graphs is that different software programs draw them differently. PowerPoint is in the same suite of programs as Excel but earlier versions of PowerPoint did have a default gap depth of zero. Therefore, the usual value of a 3D bar graph drawn using these versions of PowerPoint was read from the back of the bar. Figure 12 (left) shows a figure from PowerPoint 2003 (not the same data as in Figures 11). A number of software programs show the value from the front of the bar as in the arrow of the A bar in Figure 11 and in Figure 12 (right). Even different versions of the same software may have different defaults. We find it unacceptable that the way to read a figure

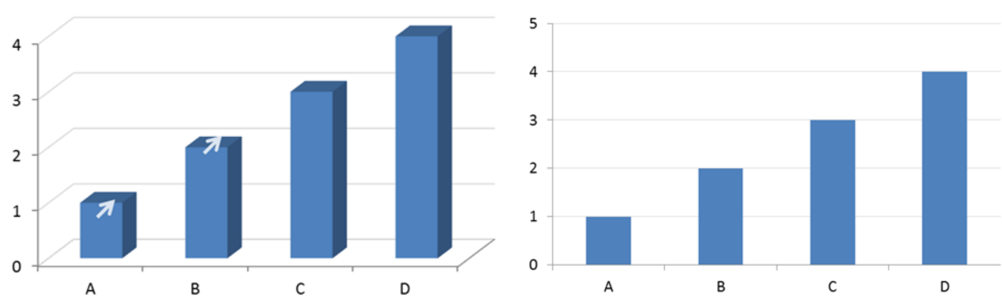

Figure 11: Many readers are not sure how to read an Excel 3D bar chart (left). An Excel 2D bar chart is much clearer (right).

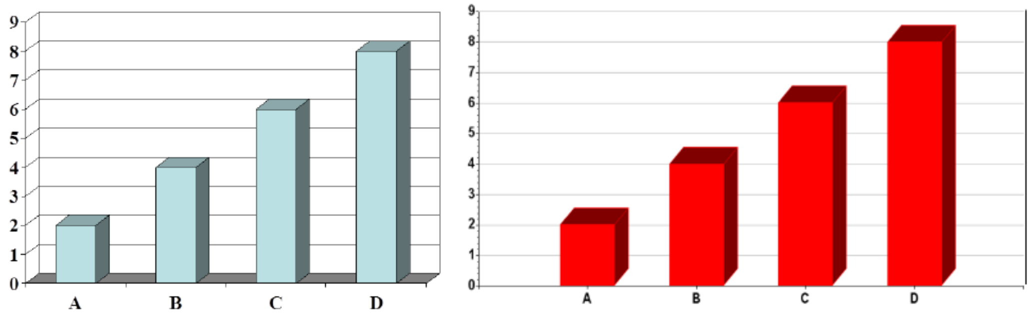

Figure 12: With PowerPoint 2003 you read from the back of the bar (left). With Presentations and Charts you read from the front of the bar (right).

should depend on the software used to draw it. Readers often don't know what software was used and even if they did, they probably don't know the algorithm used.

Each dimension of a graph represents one variable of the data. In Figures 11 and 12, we know which group the data point belongs to (A, B, C, or D) and we know the value as represented by the height of the bar. Adding a third dimension suggests that we know a third thing about the data. Since this is misleading, it is our third objection to 3D bar graphs.

3D pie charts distort the data. The wedges in the front appear larger than they should since the height of the wedge emphasizes them. People are not very good at estimating angles so the data labels are necessary to communicate the values. We are primarily communicating through the labels rather than from the chart itself, such as in Figure 13.

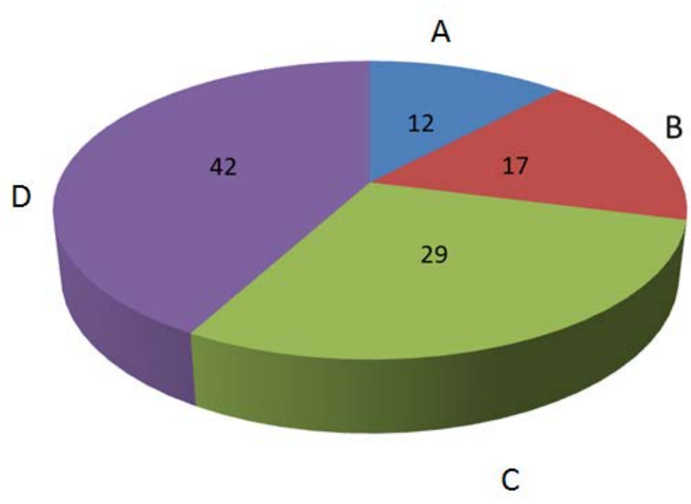

Figure 13: 3D pie charts distort the data.

3. Possible Explanations for Suboptimal Graphs

There are at least three possible explanations why we see so many suboptimal graphs among the winners of the ASA *Poster Competition*: (i) Many teachers of statistics do not know graphs well. (ii) Many statisticians, including the judges do not know details of graphs very well. (iii) Some of the documents made available at the ASA *Poster Competition* web page (`http://www.amstat.org/asa/education/ASA-Statistics-Poster-Competition-for-Grades-K-12.aspx`) contain suboptimal graphs themselves.

With respect to (i), several studies exist that assess the statistical knowledge, including the knowledge of graphs, of statistics teachers. Often, teachers of statistics lack basic knowledge they are expected to teach. Jacobbe and Horton (2010) indicated: *"At the beginning of this paper, we listed several standards that NCTM suggests that all students in the United States should master during Grades 3–5 (ages 9–11). Sadly, we discovered that the teachers in this study had not mastered these ideas themselves."* More specifically, Pfannkuch (2006) observed the following with respect to box plots: *"In this paper a secondary teacher's reasoning from the comparison of box plot distributions during the teaching of a Year 11 (15–year–old) class is analyzed. From the analysis a model incorporating ten distinguishable elements is established to describe her reasoning. The model highlights that reasoning in the sampling and referent elements is ill formed."* It should be noted that Pfannkuch's article originated from New Zealand. But, it is not difficult to imagine that similar observations also could have been made if such a study would have been conducted in the United States. Hill et al. (2005) indicated that *"teachers' mathematical knowledge was significantly related to student achievement gains"* and that their *"finding provides support for policy initiatives designed to improve students' mathematics achievements by improving teachers' mathematical knowledge."* Moreover, many teachers of statistics are not even formally trained in statistics, but may have been educated in mathematics, physics, biology, psychology, and others, and then are expected to teach basic statistical content, including statistical graphs.

With respect to (ii), Gordon and Finch (2015) observed: *"we compared graphs published in top–rated applied science and statistics journals, evaluated for overall quality and against five principles of graphical excellence. Nearly 40% of the 97 graphs we sampled were rated as poor, with no striking differences between the applied science and statistics graphs."* Clearly, when top–level academic statisticians frequently publish poor graphs themselves, how can we expect that the judges of the ASA *Poster Competition* even recognize what a suboptimal graph is?

With respect to (iii), Gabrosek and Rogness (December 3, 2007) provided a webinar how to create a statistics poster, including an extended section how to display data graphically. The webinar and the slides from the webinar are accessible at `http://www.amstat.org/asa/files/ppts/EDU-PosterCompetitionWebinarSlides12-03-07.ppt` and likely have served hundreds, if not thousands, of students and teachers as useful guidelines. While Gabrosek and Rogness (December 3, 2007) included several excellent examples of past winners (up to 2007), unfortunately, they also included at least three posters with suboptimal graphs. Two of those are shown in Figures 14 and 16. A third one that contains two 3D bar charts, but otherwise seems to be fine, is featured on slide 36 in Gabrosek and Rogness (December 3, 2007), but has not been reproduced here.

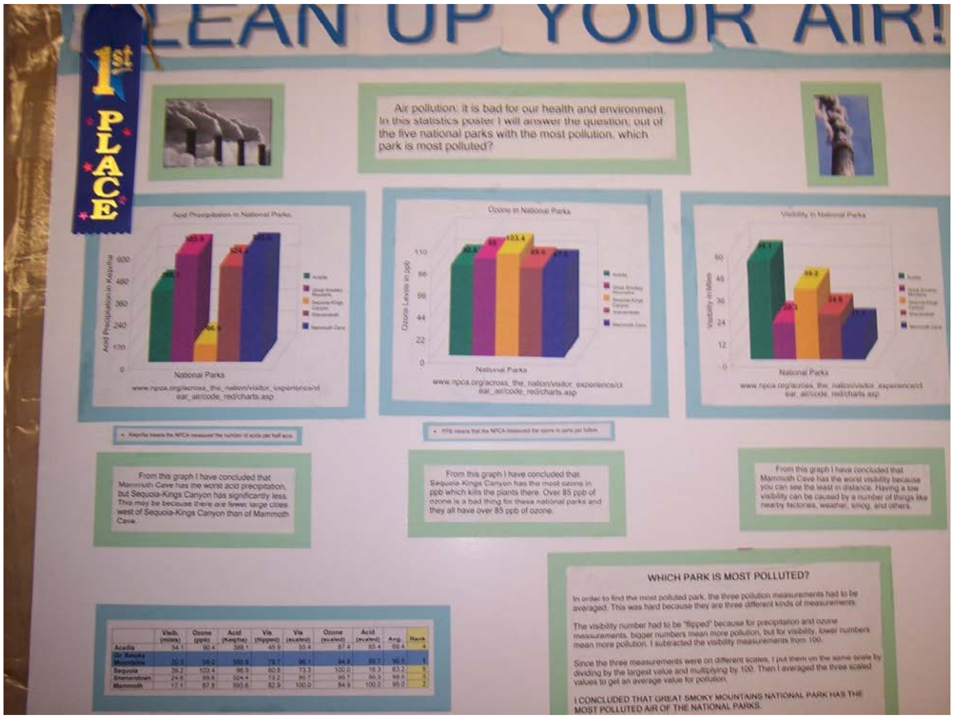

Figure 14: Poster extracted from slide 31 of "Working with K–12 Students to Create a Statistics Poster", December 2007. This poster tells a coherent story with relevant illustration and graphs. The judges awarded it First Place. We have several graphical presentation comments. This poster contains three 3D bar charts where 2D bar charts are called for. Each plot shows no spaces between bars when the discrete nature of the horizontal scale, a list of National Park names, indicates that spaces would improve the interpretability. In all three bar charts, the spacing on the vertical axis is non–standard with tick marks at intervals of 120, 22, and 12 units respectively. More standard would be decimal–based intervals such as 100, 20, and 10. The labeling of the numerical value on the top of each bar has two perceptual difficulties. It artificially changes the visible height of the bars. It is difficult to read (especially in the dark blue bars) because it clashes with the color scheme of the bars. The National Park bars are ordered horizontally. The legend on the right is ordered vertically. All three panels have captions that are isolated in separate boxes from the graphs themselves. The first two panels have notes that are also isolated in different boxes. We show our redrawn "Acid Precipitation" graph in Figure 15.

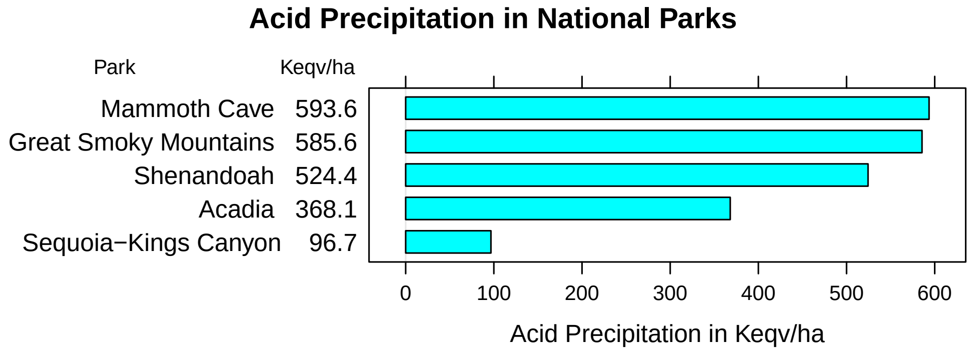

Figure 15: We show the "Acid Precipitation" panel from Figure 14 as horizontal 2D bars. Multiple colors are not needed. The tick labels on the horizontal axis have 100 unit increments. Both park names and precipitation measures appear on the left tick labels. The bars have been sorted from highest (top) to lowest (bottom) acid precipitation.

Figure 16: Poster extracted from slide 37 of "Working with K–12 Students to Create a Statistics Poster", December 2007. This poster contains one 3D cone plot (bottom right). The low resolution of the reproduction of this poster makes it difficult to make a definite assessment, but it appears as if two of the bar charts (center left, bottom left) do not start at 0, but at 18.5 and 18, respectively.

4. Future Plans of the Task Force

Our task force is planning to continue its ongoing interaction with the *ASA/NCTM Joint Committee*. Based on this reassessment of the winning posters from the annual ASA *Poster Competition* and pointing out common mistakes in graphs from these posters, these are the likely next steps: (i) Help with the update of the ASA *Poster Competition* web page with respect to good and suboptimal graphs, possibly leading to an online booklet or tutorial for future contestants, teachers, and judges. (ii) Preparation of a "Good Graphs" webinar. (iii) Preparation of some "hands–on" guidelines how to create good graphs, using software that is widely used in schools, such as the free Core Math Tools software from NCTM (`http://www.nctm.org/coremathtools/`), Chris Wild's Inzight software (`http://lite.docker.stat.auckland.ac.nz/`), and the Fathom software (`http://fathom.concord.org/`). (iv) Preparation of a derivative of this article, aiming at teachers and K–12 students. Your input is always welcome — please contact us via e–mail with suggestions and comments!

5. Sources for Constructing Better Graphs

A variety of easy–to–understand, but fun–to–read textbooks and articles exist that motivate good and not so good graphs, such as the textbooks from Wainer (Wainer, 1997, 2005) and his numerous articles published during the last 30 years (e.g., Wainer, 1984, 2007, 2008, 2009). Robbins (2013) and Wallgren et al. (1996) both presented good graphs and featured related bad graphs that should be avoided. Clearly, some of the work from Tufte (in particular, Tufte, 1997, 2001) is of interest to readers of all ages and backgrounds. A classic to read is Huff and Geis (1993), including some early insights into deceptive graphs, although we don't completely agree with the chapter on the "Gee–Whiz Graph". Su (2008) provided some insights why it is so difficult to produce good graphs with Microsoft Excel. Cleveland's books (Cleveland, 1993, 1994) and articles (e.g., Cleveland and McGill, 1984) are a source for more advanced readers and may be of interest in particular for the judges of the ASA *Poster Competition*.

We also would like to bring your attention to the following blogs:

- Camoes, J. "ExcelCharts,"
  `http://www.excelcharts.com/blog/`
- Peltier, J. "Peltier Tech Blog — Peltier Tech Excel Charts and Programming Blog,"
  `http://peltiertech.com/WordPress/`
- Qiu, L. (October 1, 2015). "Chart Shown at Planned Parenthood Hearing is Misleading and 'Ethically Wrong'," Politifact.
  `http://www.politifact.com/truth-o-meter/statements/2015/oct/01/jason-chaffetz/chart-shown-planned-parenthood-hearing-misleading-/`
- Robbins, N. B. "Effective Graphs,"
  `http://www.forbes.com/sites/naomirobbins/`
- Robbins, N. B. (February 28, 2012). "Misleading Graphs: Displaying a Change in One Variable Using Area or Volume," Forbes.com LLC.
  `http://www.forbes.com/sites/naomirobbins/2012/02/28/misleading-graphs-displaying-a-change-in-one-variable-using-area-or-volume/`

- Wyatt, S. (March 31, 2014). "Dishonest Fox Charts: Obamacare Enrollment Edition," Media Matters for America.
  `http://mediamatters.org/blog/2014/03/31/dishonest-fox-charts-obamacare-enrollment-editi/198679`

6. General Discussion

While the focus of this article was on pointing out common problems that have been found in various graphs from the winning posters of the ASA *Poster Competition* from 2013 to 2016, we want to emphasize that the majority of graphs in these posters were very well done. There were instances where we asked ourselves "wow, was this really done by someone from Grade 7–9"?!? So, we would encourage students, teachers, and judges to focus even more on posters with excellent graphs in the future. Clearly, having various documents accessible on the ASA *Poster Competition* web site that focus on excellent graphs in posters would further help to achieve this goal.

As a final note, we would like to mention that the statistical graphics community in general considers pie charts and bubble charts as less optimal than some other graph types. For example, pie charts always can be replaced by bar charts. In bubble charts, estimating the actual values (if not overlaid as text on the graph), is rather difficult for most human readers. Instead, a chart where bars representing the values are placed on the positions of the bubbles would be much easier to interpret.

Acknowledgment

Photos of the posters are courtesy of the American Statistical Association. The full posters containing these graphs were published in *Amstat News*, August 2013, August 2014, August 2015, and August 2016.

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