Simple Computer Graphing Assignment Becomes a Lesson in Critical Thinking[1]

Jonathan G. Leonard[2] *and Thomas F. Patterson*[2]
University of Vermont
Burlington, VT 05405

Abstract

We have learned that to analyze, interpret and communicate information through a graph is both a "science and an art" in critical thinking. Faculty in the College of Agriculture and Life Sciences at the University of Vermont require all first year students to take a semester-long course in information technology, which includes a major section on data interpretation and graph construction. Through pre-testing and a comprehensive analysis of graphing assignments, it was determined that first year students have difficulty constructing proper graphs. Common graph types and their usage are discussed. A frequency ranking of student graphing errors indicates that graphing problems are related to a combination of factors involving the software, the student, and the instruction. Suggestions for improving instruction include having students understand the data they intend to graph and the message they wish to communicate, and visualize their graph before using software to create the graph.

Introduction

Some could argue that the agricultural revolution was made possible by talented and detailed record keepersthose who kept meticulous track of each seed planted, each animal domesticated, the yield of each variety tried. The Bible, Near Eastern monuments, and Chinese, Greek and Roman writings all serve as historical testaments to the development of agriculture (Heiser, 1990). Modern agriculture could not exist without record keeping; indeed the computer is essential in every aspect of today's agriculture, from research to production to distribution. Mendel's hand-kept notes have been replaced by massive data sets that can only be handled by today's sophisticated information technology. While the challenge of storing raw information has largely been met, understanding, interpreting and communicating the meaning of these data is a different story.

Faculty in the College of Agriculture and Life Sciences (CALS) at the University of Vermont (UVM) have adopted a core curriculum (Patterson et al., 2001) that includes a semester-long course requirement in information technology for all first year students, so they may apply and build on these skills during their subsequent years at UVM and beyond. One major objective of the information technology course (AGRI 195 Foundations: Information Technology) is to teach students to accurately analyze, interpret and communicate data through graphs.

UVM and our Students

UVM is part of the land-grant college system (Justin Morrill was Vermont's Senator). The College of Agriculture and Life Sciences (CALS) has about 750 undergraduate students, 70 graduate students, and 70 faculty in six academic departments (Animal Sciences, Botany and Agricultural Biochemistry, Community Development and Applied Economics, Nutrition and Food Sciences, Plant and Soil Science, and Microbiology and Molecular Genetics [http://www.uvm.edu/cals/]). Every fall for the past five years, CALS has enrolled between 150 and 200 first year students.

Most of our undergraduate students enter CALS with considerable experience using personal computers, especially Microsoft Office programs including Word® and Excel®. Results from a "knowledge quiz" that is administered during the first weeks of the semester show that out of 148 first year students, 87 (59%) said they were familiar with Excel®, and 22 others (15%) said they were familiar with other spreadsheet and graphics software packages. Only 39 (26%) claimed they were not familiar with spreadsheet and graphics software. These summary statistics of first year students are similar to those reported by the University of Arkansas (Johnson et al., 2002). The majority of our students rated themselves between beginner and intermediate when asked how "proficient" they were at spreadsheets and graphics. This self-rating was supported when students were tested on specific questions about proper graphing techniques. Upon review of AGRI 195 graphing assignments using Excel®, a very high percentage of our students made significant graphing errors.

These errors included choosing the wrong type of graph for their data, having a bar (in a bar graph) or slice (in a pie graph) for a total when it was inappropriate, and trying to include too much data on a single graph. Out of the 134 graphing assignments we analyzed, only three were without significant problems!

We were interested in finding out what were the

[1] The authors acknowledge Meg Ashman, Jane Kolodinsky, and Susan Patterson for their reviews of the manuscript.
[2] Department of Community Development and Applied Economics,

most common graphing errors that first year undergraduates make in CALS and how we could modify our teaching to address these problems.

Common Graph Types

Graphs give life to static spreadsheet tables and make data more interesting and useful by bringing to light patterns in the data that are hidden or obtuse in the spreadsheet format. Graphs show trends and relationships among data that are often lost in the obscurity of a table of numbers (Figure 1)

The type and amount of data, and the story the graph maker wants to tell, will determine the kind of graph to be chosen. What follows is a brief summary of common graph types and their uses. Details of graph construction and usage are found in texts by Cleveland (1985), Henry (1995), Schmid & Schmid (1979), and Wallgren et al. (1996).

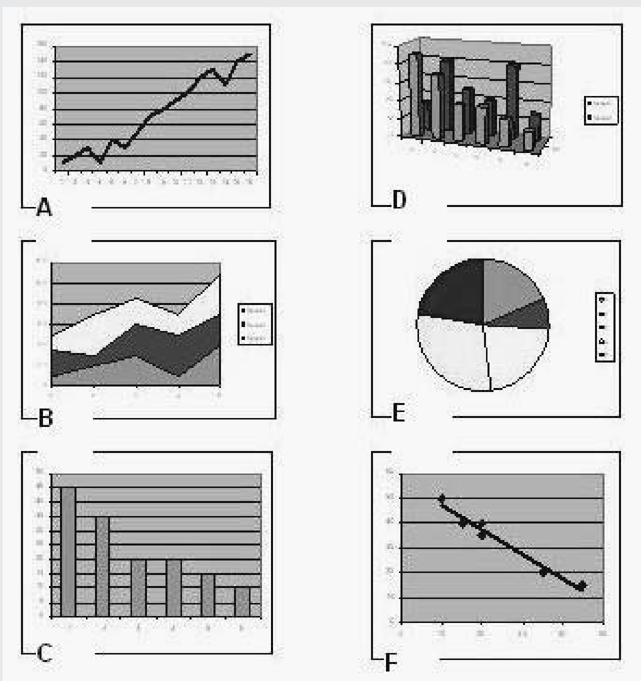

Figure 1 Common Graph Types: (A) Line and 3-D Line; (B) Area and 3-D Area; (C) Bar or Column; (D)3-D Bar; (E) Pie; and (F) XY Scatter Plot.

Line and 3-D Line: Line graphs are most often used to plot changes in data over time. Each line represents a category of data, and each point along the line represents the data's value at a particular time. Time series data such as changes in the elevation of Lake Michigan over the year, or changes in the number of bacteria per ml over a day, should be graphed as a line graph.

Area and 3-D Area: Area graphs are a variation of the basic line graph in which the lines are stacked and the areas between the lines are filled with different colors or hatch patterns. These graphs show the contribution of one set of values to the whole.

Bar or Column: Bar or column graphs consist of a series of bars, each one representing the value of a particular category. If the data do not have any inherent order, the bar is the graph of choice. Bar graphs are often used to compare related data at a given point in time. In almost all cases, the bars should be sorted in ascending or descending order. Stacked bar graphs compare different sub-sections of a whole, for example the relative size of voter turnout from each political party during presidential elections in the U.S.

3-D Bar: Adding a third dimension gives visual interest to a bar graph and may allow the graph maker to highlight comparisons by placing one row of bars in front of another.

Pie: Pie graphs are used to show the proportion of two or more values to a meaningful whole. The pie slices will be proportional to the percentage each value contributes to the total. For example, the percentage of the human population that was distributed across the continents in 2003 should be graphed as a pie graph.

XY Scatter Plot: XY graphs, also called scatter plots, are used to show correlation or relationships between different sets of data. Often the two sets of data have very different scales of measure, so a bar graph would not work. For example, an XY scatter plot should be used to show the correlation between birth rate and GNP per capita for selected countries.

While selecting the correct graph type is paramount, labeling is also critical to making an appropriate and effective graph.

In over 20 years of teaching information technology to undergraduate students, we have come to the conclusion that constructing an appropriate and effective graph is both a "science and an art" in critical thinking (There is a myriad of definitions for critical thinking. For this article we are defining critical thinking as the purposeful, reasoned and goal-directed thinking involved in solving problems, formulating inferences, calculating likelihoods, evaluating alternatives, and making decisions [Halpern, 1984]). It is a "science" in that a reasonable conclusion must be drawn from a set of data and an appropriate graph must be selected, constructed, and labeled correctly so that the conclusion is communicated clearly. Graphs often communicate statistical information used in hypothesis testing and making inferences based on probabilities. Constructing a graph is an "art" in that the amount of data to be displayed and the visual "look and feel" of the graph are decisions that follow only general aesthetic and subjective guidelines. The graph designer must find a balance between details and the whole, keeping in mind it is what the reader perceives that is important, not how much can be included in the graph. Additionally, graphs speak directly to the eye and create a compelling picture of the data in the reader's mind. It takes artistic skill to bring out the meaning and patterns in the data most effectively. Just as a good graph conveys information, a bad graph misleads the reader (Wallgren et al., 1996).

We have found that sophisticated programs like Excel®, while giving our students an incredibly powerful, easy-to-use graphing tool, also provide an almost unlimited opportunity to produce unsuitable, misleading, incomprehensible and, at times, comical graphs.

Methods

We gathered data on the type and frequency of graphing errors by reviewing 134 graphs from all nine lab sections that were submitted to fulfill the graphing assignment for the fall 2002 semester of AGRI 195. For this assignment, students were to select and graph student profile data found on UVM web sites developed by the Center for Teaching and Learning, Institutional Studies and the Office of Financial Analysis and Budgeting. These data include student demographic and enrollment information and the results of student surveys and student opinion polls.

We carefully examined each of the 134 graphs and tallied errors on a checklist of common graphing errors we developed. When a new error category was observed, we added it to the checklist.

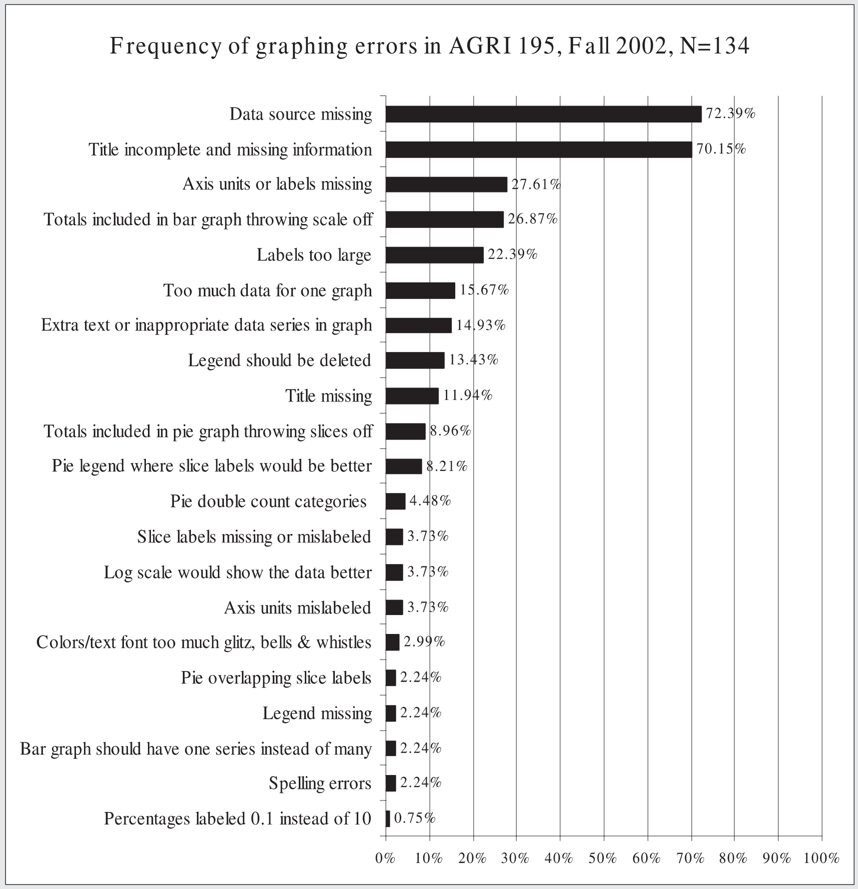

Figure 2. Horizontal bar graph showing frequency of errors in first year student graphing assignment, CALS, UVM, Fall 2002.

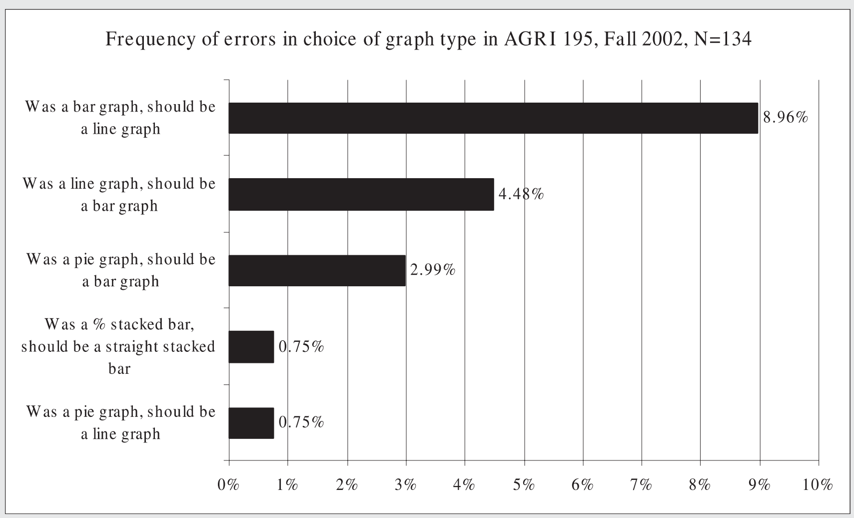

Figure 3. Horizontal bar graph showing frequency of errors of graph type in first year student graphing assignments, CALS, UVM, Fall 2002.

Results and Discussion

The graphs submitted for the graphing assignment in the Information Technology class clearly indicate that our first year students have not yet developed the critical thinking skills necessary for constructing appropriate graphs to display information. Figures. 2 and 3 detail the frequency of errors found in 134 graphs submitted by the fall 2002 AGRI 195 Information Technology class. It is notable that none of the students chose to compose an XY scatter plot, although the data to do so were available. Based on later exercises in lab we observed that most of our students do not understand how to construct, and have difficulty interpreting, XY scatter plots.

There were mistakes made in both the "science and art" of graph making. For example, in terms of "science," students selected the wrong graph type, omitted a necessary legend, forgot to include a data source, and made spelling errors that made it difficult or impossible to make an inference or reach a conclusion from the graph. In terms of "art," students selected too much data for one graph, added unnecessary information or distracting embellishments, left pie slice labels overlapping, and created labels that were too large for the graph. We believe that an ever varying combination of three factors - the software, the student and the instruction - accounts for the myriad of problems found in this graphing assignment.

Software: Clearly the software has limitations - in the choices of graphs available, the step-by-step graphing construction defaults or graph wizards, and the amount of customization available to the student. The software may simply make it difficult to include a necessary element in the graph; for example, we have found that adding XY scatter plot point labels in Excel® is tedious and extremely time consuming. Also, the software default may be inappropriate for the chosen graph (Excel®'s default is to add a legend to a bar and line graph even when one is unnecessary) or the software may allow for too many options, leading to student uncertainty and confusion.

Student: The student, of course, bears a great deal of responsibility. The student must make critical choices ranging from hard and fast rules of graph choice to ever so subjective aesthetic decisions on the "look and feel" of the graph. Student error and carelessness also plays a role here and, frankly, may simply reflect the intellectual development level of an eighteen year old first year student. Students also may assume that if the software lets them construct the graph, then it must be correct.

Instruction: The failure of first year students to grasp the intricacies of graph construction must be born by the instructors as well. AGRI 195 students attend one 90-minute lecture and one two-hour lab each week. Instruction for each week's Information Technology assignment is mainly done in the lab by upper-class Teaching Assistants (TAs). The professor reviews the lesson with the TAs a week before in a special TA class. The lab instruction consists of creating a simple spreadsheet budget in Excel® and constructing pie and bar graphs from subsets of the budget data.

Suggestions for Instruction

Our review of student graphs and the instruction process has pointed out a number of shortcomings that need to be addressed in future instruction. We have spent too much time on demonstrating what the graphing software can do, and not enough time on the critical thinking aspects of graphing. Students need practice in the "science" (drawing a reasonable conclusion from a set of data and constructing an appropriate graph) and the "art" (creating a clear and compelling visual message for the reader). Because students often follow the software wizard defaults without critically thinking, we now believe that students need to select a set of data and visualize the graph first. After sketching the graph on paper students should use the graphing software, rather than allowing the program to make the graph for them by accepting the step-by-step graph wizard defaults of Excel®. One way to do this is to give students exercises where the instructor supplies the data and the students have to first explain the message they are trying to communicate and then draw by hand what the graph should look like. Below are five in-class exercises to give students practice with choosing the appropriate graph type for a given set of data, explaining the conclusion or message to communicate, and visualizing the graph before using the graphing software:

1. Imagine you are investigating blood cholesterol level and diet. You collect the following data from 1000 patients. What graph would best communicate the data? Draw what the graph should look like. Describe the conclusions you would draw from the graph.

Patient Number	Blood Cholesterol Level (mg/dl)	Average Grams Peanut Butter per Week	Average Grams Tofu per Week
1	207	56	5
2	150	43	18
3	212	0	34
4	211	87	0
.	.	.	.
1000	175	23	11

2. You are trying to figure out how literacy rates have changed in Honduras between 1950 and 2000. What graph would best communicate the following data? Draw what the graph should look like. Describe the conclusions you would draw from the graph.

Year	% Literacy of Men	% Literacy of Women
1950	45	18
1951	45	19
1952	46	19
.	.	.
2000	55	21

3. You are trying to find out if year of women suffrage is at all related to the percent of woman who are literate. You gather data from all the countries of the world. Draw what the graph should look like. Describe the conclusions you would draw from the graph.

Country	Year Women Suffrage	% of Women that are Literate in 2002
Albania	1948	47
Australia	1921	100
Austria	1918	98
.	.	.

4. You want to show the age distribution of people in Costa Rica in graphic form. What graph would best communicate the following data? Draw what the graph should look like. Describe the conclusions you would draw from the graph.

Between Ages	% of Population
0-5	8.2
5-10	7.6
10-15	6.1
.	.
90-95	0.03

5. You are investigating the effect of acetaminophen on heart rate in rats. You run your experiment on 1000 rats. How would you graph the following data? Draw what the graph should look like. Describe the conclusions you would draw from the graph.

Rat Number	Heart Rate Resting (B/min)	Dose 5mg	10mg	15mg	20mg	25mg	30mg
1	200	198	203	197	201	215	208
2	223	227	224	194	235	245	213
.	.	.	.	.	.	.	.
1000	215	218	217	220	221	213	218

Exercises such as the above should be done before introducing students to the graphing software. Also, with the help of the professor and TAs, students should critique the science and the art of many graphs that have errors so they learn to recognize and correct errors in their own graphs.

We also need to coordinate lecture and lab better, increasing the amount of time in lecture and lab spent on working with data, choosing data sets, selecting the most appropriate graph type for the selected data set, focusing on the "look and feel" and the visual message of the graph, and establishing aesthetic criteria for graph construction. Adding a checklist for students to use in their graphing assignment may help to cut down on carelessness and simple omission mistakes.

Summary

A graph is a visual communication medium that gives life to data by displaying patterns and relationships that are often hidden in a spreadsheet format. Students tend to accurately estimate their inability to use graphing software and we, as IT instructors, have been inclined to underestimate the visual, subjective nature of graph construction. Focusing instruction on what the graphing software can do has led to a large number of student errors. This analysis has established that the seemingly simple task of teaching undergraduate students how to construct a graph is actually a sophisticated assignment in the "science and art" of critical thinking. Students not only have to draw conclusions from a data set and construct an appropriate graph, they have to pay attention to the "look and feel" of the graph. Attention should also be paid to the aesthetics and visual message of graph construction.

Literature Cited

Cleveland, W.S. 1985. The elements of graphing data. 1st ed. Monterey, CA: Wadsworth.

Halpern, D.F. 1984. Thought and knowledge: An introduction to critical thinking. 1st ed. Hillsdale, NJ: Lawrence Erlbaum Associates.

Heiser, C. B. 1990. Seed to civilization: The story of food. Cambridge, MA: Harvard University Press.

Henry, G.T. 1995. Graphing data: Techniques for display and analysis. London: Sage Publications.

Johnson, D. M., J. A. Ferguson, and M.L. Lester. 2002. Computer experiences, self-efficacy and knowledge of students entering a college of agriculture. NACTA Jour. 46(1): 58-67.

Patterson, T., J. Leonard, and W. Harper. 2001. A core curriculum for the 21st Century. NACTA Jour. 45(4): 13-20.

Schmid, C.F. and S.E. Schmid. 1979. Handbook of graphic presentation. NY: John Wiley & Sons.

Wallgren, A., B. Wallgren, R. Persson, U. Jorner, and J. Haaland. 1996. Graphing Statistical & Data. Newbury Park, CA: Sage Publications, Inc.