



## Using Graphics in Scientific Writing\*

### Definition and Purpose of Graphics

The term *graphics* refers to pictorial illustrations designed to accompany a text. Often such illustrations consist of words, numbers, and pictorial elements together. *Graphics* include a broad range of illustrations, from the intricately drawn and richly illuminated capital letters on medieval manuscripts to the ubiquitous “smiley face” and its variations, all designed to lend specific tonal or emotional qualities to the texts they accompany. In contrast, science writers restrict their use of graphics to the objective, quantified representation of significant data upon which experiments and findings are based. Science graphics help the reader visualize and therefore better understand the significant evidence for a text’s claims. In certain cases, such as a photograph of a previously unknown organism or structure, graphics can also provide a form of documentation.

Of the many sorts of pictorial illustrations which may accompany texts, science writing relies primarily on these particular graphics: charts, tables, diagrams, line drawings, and photographs. These graphics share a common characteristic that serves the presentation of scientific information very well: They can be designed to maximize the amount of precise, detailed, complex information a reader can understand but do so in a relatively small space and in a relatively short time. In other words, science graphics are essentially *economical*, a desirable feature of science writing. Ideally, science graphics should be simply designed so they are accessible to the reader, but at the same time, they should offer the reader complexity of detail.

However, it is important to keep in mind that whatever their level of detail, graphics *support* a text; they are not an argument or an explanation

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\* Patricia Hartz of the University of California, Irvine, wrote this chapter.

in and of themselves. Therefore, the writer must take care to *interpret and explain the significance of the graphic within the text*, at the place where the writer refers to the graphic. Furthermore, graphics alone should not be used to explain, evaluate, interpret, refute or review data—the text itself should fulfill those functions. Graphically depicted data provide a text with evidence, but it is still up to the writer to explain its significance to the reader.

## General Principles of Graphic Use and Design

Science writers select a graphic design based on their specific purpose, but there are some general principles of good graphic use that science writers should follow to ensure the quality and accuracy of the graphics that accompany their texts. Regardless of the specific kind of graphic a writer selects, the following principles should guide its design.

1. Graphics impose upon a reader's time, so they should always serve a clear function and should never be introduced gratuitously into a text. However, they should be included when the writer needs to convey complex information and when patterns and trends of data provide significant evidence for a claim.

2. Graphics should present data clearly and concisely, show complex relationships accurately, and provide the reader with an appropriately labeled, coherent picture of the data set. Remember that a graphic tells a visual story about the data, and like any other story, it must be clear and coherent in order to be understood, and all the characters must be given a name.

3. Graphic elements and design should focus the reader's attention on the values, patterns, and trends of the *data* rather than on the *design* of the graphic. Writers should avoid content-free decoration such as frames or borders, unnecessary symbols, and the use of color, shading, or other technical effects which do not correspond to or represent actual data. Graphics should demonstrate *the significant variation of data*, not unnecessary elaboration of design.

4. Graphic design must never distort or falsify the data. The following two rules should be strictly followed in designing a graphic:

a) The number of variable dimensions represented in the graphic should not exceed the number of dimensions in the data.

b) The representation of numbers on the graphic should be directly proportional to the numerical qualities represented, ensuring that the graphic gives an accurate representation of scale.

5. Graphics must be placed in the text so that they are closely integrated with the statistical and/or verbal descriptions of the data set they represent. Data should not be quoted or referred to out of context, forcing the reader to riffle through pages trying to find the supporting graphic.

## Manuscript Conventions for Graphics

Text and graphic should be run together whenever possible, but graphics should not be set off with unnecessary lines or other intrusive or distracting marks or frames. When possible, graphics should be laid out horizontally, slightly greater in length than in height, at a proportion of approximately 1:1½. These proportions are both aesthetically elegant and encourage the reader to focus on the data in the same manner that readers generally read, from left to right. Unless the pattern of the data itself makes another shape desirable, the standard proportions should be used.

Graphics large enough to take up their own page should fit within the standard 1" margin, just as the text does. Oversized graphics should be neatly folded to fit the size of the text and appended to the end of the text, and the location of the appendix should be indicated in the relevant paragraph in the text. Graphics not central to the text but of more general information should be placed at the end of the text in a separate appendix and given a descriptive title.

All graphics require descriptive, economical but complete titles, and clear, detailed, thorough labeling. The labels should be written on a graphic from left to right whenever possible and preferably in straight lines; angled labels should be avoided because they are difficult to read. Title and labeling words should be written out in full except for standard abbreviations (psi or cm, for example); other codes and symbols should be avoided. Science writers do not ordinarily use graphics that require legends. Instead, they design graphs so that all values are represented directly on the graphic itself. In other words, a graphic should be appropriately designed and sufficiently labeled so that no legend is needed. However, important events or values may and in many cases should be annotated or identified on the graphic itself. Explanatory information can also be included in notes at the bottom of the graphic.

The same typeface used for the text should be used for its graphics, and the typeface should have serifs. Though block letters may appeal to the lay person as appearing more "scientific," in fact, the block style is neither intrinsically nor conventionally scientific, and perceptual studies suggest that readers have greater difficulty distinguishing block letters than those with serifs. For a similar reason, the title, labels, and abbreviations, or any words on the graphic should have *both* capitalized and lowercase letters. STUDIES SUGGEST THAT WORDS WITH ALL CAPITALS ARE MORE DIFFICULT TO READ, AND THEY ALSO GIVE THE EFFECT OF YELLING AT THE READER. In contrast, using type with serifs, and using the standard rule of capitalizing only the first letter of title words (except for articles and prepositions), give readers the greatest ease in character recognition.

As another convenience for the reader, graphics should be numbered consecutively in a text, unless the text contains only one graphic, in which

case no number is needed. If the text contains more than one graphic, and those graphics are a mixture of types (a table, a chart, and a diagram, for example), refer to the graphics as "Figure 1," "Figure 2," etc. The figure number, followed by a colon, precedes the title of the graphic.

**Exercise 1:** Go to the library and examine a copy of *Science* and a copy of *Scientific American*. Focus specifically on the sorts of graphics accompanying the texts. What differences in graphics between the two publications do you notice? Write a paragraph in which you identify the differences and explain them based on the audiences they address. (Hint: Refer to Chapter 3). Which addresses the more general audience? What makes you think so?

**Exercise 2:** Assume the following graphic (below, p. 117) is the only one accompanying a text. Examine it closely. How many principles of good graphic use does it violate? List as many as you can. How does each violation interfere with the reader's understanding?

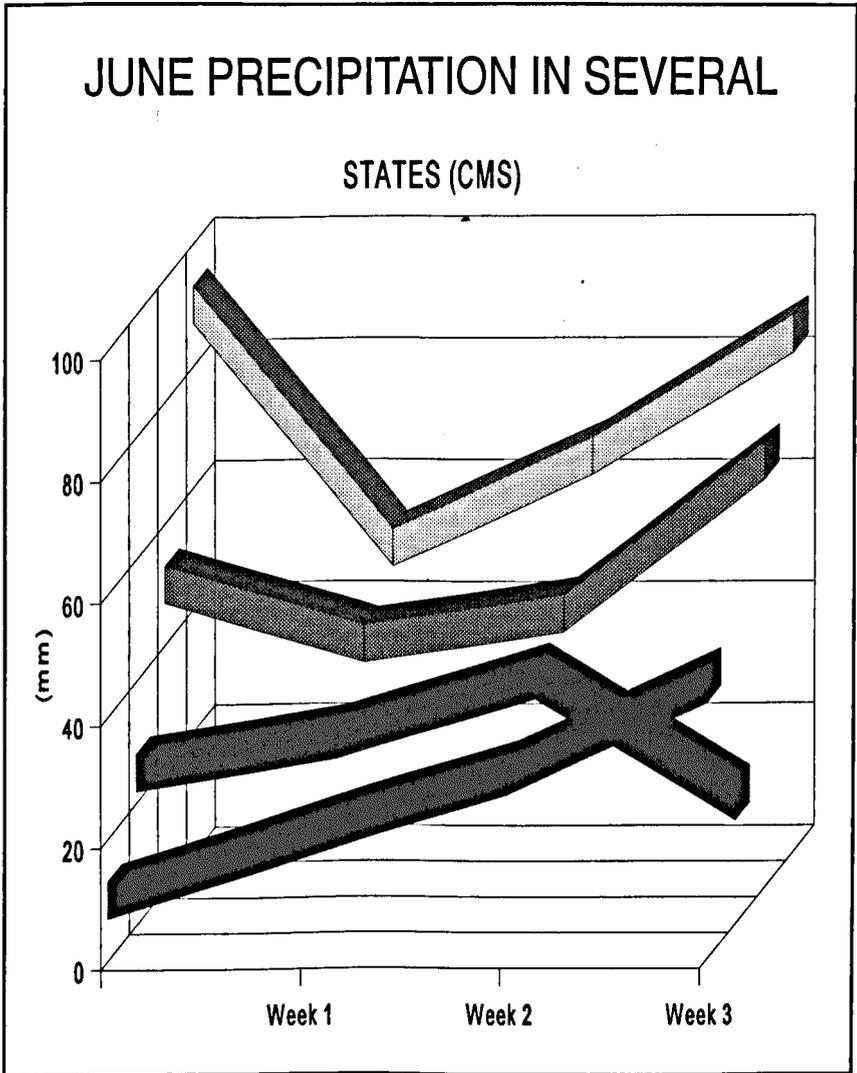
### Integrating Graphics and Texts

It is absolutely essential that the science writer understand that the functions of graphics and the written text are different and hierarchical: Graphics *serve as evidence* for the written text. They *support the written text*, but they do not constitute an argument in and of themselves. In order for evidence to be meaningful to the reader, its *significance to the writer's discussion or argument must be made clear*. Therefore, the writer must integrate references to graphics into the written text so that the reader (1) can find them quickly and easily, (2) has a description of the experiment on which the data is based, (3) has the relevant pattern or trend of the graphic identified and explained, and (4) is given the conclusions suggested by the data.

The reader can find the correct graphic easily if the graphic is clearly numbered and near the paragraph referring to it. The reference should be placed in parentheses. For example, "(See Table 9)." The graphic should not be referred to until the experiment or event on which the data is based has been described. Then the significant pattern that the data represents should be explained. Immediately following this, the graphic should be referred to in parentheses. But the logic which connects the graphic and writer's conclusion based on the data must be given to the reader, since the data cannot argue itself.

### Titling Graphics

Titles for graphics in science writing are not optional; they are important pieces of information your reader needs in order to understand the significance of graphical data for your discussion. Graphics which are not identi-



fied by a title are more likely to confuse the issue for your reader than they are to clarify it. Well-selected titles contribute to the reader's understanding when they uniquely distinguish *each* graphic by describing the data represented.

Describing the graphic in a title is not as easy as it sounds. Beginning writers are likely to confuse a descriptive title with a conclusion drawn from the data. For example, say you experiment with the effect of hours of sunlight on the growth of a plant. You gather your findings and create a chart that represents them. The chart shows the growth of the plants in relation to the number of hours of sunlight the plants were exposed to at

different times. The data suggests that the effect of decreasing sunlight is to slow down the plants' growth. What would a good title for such a chart be? It would *not* be "Decreased Sunlight Retards Plant Growth." Why? Because this title does not describe or identify the graphic data at all—it draws a conclusion from the represented data, and such *conclusions are part of your discussion in the text, not part of the graphic*. Avoid this error when selecting graphic titles.

Good titles have several other characteristics as well. To say they uniquely identify each graphic is to ensure that the distinctive feature of the graphic is the main part of the title. For example, assume you have created a graphic using data derived from an experiment to discover the effect of water salinity on the rate of evaporation. An appropriate title would be, "Evaporation Rates for Saline Water Solutions." Note that this title correctly uses nouns as its principal elements; this is because the function of nouns and noun phrases is precisely to name things. Other parts of speech, such as relative clauses and participles should be avoided. For example, these are not good titles: "Saline Water Solutions that Evaporate at Different Rates" or "Evaporating Water Solutions."

Sometimes subtitles are also useful to the reader. Subtitles occur in parentheses centered beneath the main title, and they should be restricted to secondary but important information. For example, if a condition of the experiment is the same for every datum represented, one could indicate that in parentheses centered beneath the main title:

Evaporation Rates for Saline Water Solutions  
(T=40°C)

Or one might choose to indicate the scope of the data—for example, "(by year)." Or the unit of measurement or analysis, "(in cm)." Or the number of test subjects, "(number of test subjects=500)."

Some general principles apply to both titles and subtitles. They should not repeat or reproduce discussion from the accompanying text, nor should they make extended comment; they should not provide irrelevant information; they should not express the writer's subjective feelings; and they should not aspire to or actually achieve humor.

Both titles and subtitles use the standard rules of capitalization: the first word is always capitalized, and all following words except for articles and prepositions. Common abbreviations for units of measurement may be used in subtitles, and need not be capitalized if they are not ordinarily capitalized: for example, "(psi)." Titles should be centered above the graphic. However, long titles are generally left-justified if they are longer than three lines.

**Exercise 1:** Devise a title appropriate for a graphic demonstrating the effect of length of sunlight on plants. Then devise an appropriate subtitle.

**Exercise 2:** Evaluate the following titles:

- a) Data Disproving Dr. Smith's Ludicrous Theory
- b) Occurrence of Intestinal Parasites in Domestic Cats  
(Suggesting Monthly Inspection of Fecal Material by Owners)
- c) Distribution of Iridium on the Yucatan Peninsula  
(Field Trip Financed by National Science Foundation Grant)

### Selecting a Specific Graphic

The first question the writer should ask is whether a graphic is necessary at all. Most *simple qualitative* relationships can be described in the text. For example, a structural engineer's description of the deterioration of steel span bridges within a county could be presented clearly without using a graphic. However, *complex qualitative* relationships might very well be better expressed in a diagram. For example, if the structural engineer wanted to represent the complexity of causes that affected the bridges being analyzed, causes such as overload due to traffic congestion at high-use periods, improper truck routing, and periodic river flooding, the engineer might very well devise a diagram such as a flow chart to clarify causal relationships for the reader.

But what if the engineer wanted to represent the number of deficient bridges found in every county in the state? When the writer wants to express *exact quantitative values*, as would be the case here, a table is the most useful graphic choice. Suppose our engineer also wanted to represent the estimated rate of deterioration on the state's worst bridges. In that case, when *quantitative patterns or processes* must be represented, a chart or graph is most useful.

If we imagine that the engineer also wants to show exactly which of the weight-bearing beams on the worst bridges are in immediate danger of collapsing because of stress faults, it is easy to see that line drawings would be the best graphic choice. Since a line drawing is a schematic image of an object that emphasizes a specific part, the engineer could show the area of deterioration clearly by eliminating the irrelevant parts of the bridge from the drawing and by making the danger zone or fracture site itself the focus. Alternatively, if the engineer discovers that rust and corrosion threaten specific bridge supports, photographs of the sites, with a scale included to allow the reader to estimate the amount of metal actually eaten away, would provide the reader with the clearest understanding of the situation.

Not only are graphics selected on the basis of the writer's purpose, but also on the basis of the nature of the relationships depicted. Most science graphics are either based on chronology (for example, a time-series or a time-space series), or they show relations between variables. The major

difference between these two types is that a time-series graphic need not necessarily suggest a causal relationship between a variable and the passage of time, but may simply *describe* a process instead. Relational graphics, however, those which show the relationship between two or more variables, frequently suggest an "X causes Y" proposition. A writer needs to consider carefully the sorts of relations being depicted to make sure that chronological relationships are not graphically expressed as causal, and vice versa, that causal relationships are not graphically expressed as mere chronological changes. In general, unless an instructor asks the student writer for a specific graphic form, or unless the writer's discipline uses specific, conventionalized graphic forms (as in computer science, for example), the writer should select a graphic type on both the basis of the writer's purpose and the nature of the data.

### Individual Kinds of Graphics

**Tables:** A table is a collection of individual pieces of information arranged in rows and columns according to category and type. Use a table to show exact numerical values and to allow the reader to make many detailed, discrete comparisons. Tables can be arranged chronologically, like a train schedule, or they can be used to represent items in order from whole to part or values from high to low. Tables are useful to the reader only if the rows and columns are designed logically and if the design allows the reader to locate the information quickly. Poorly designed and/or cluttered tables are

#### Parts of a Table

Sub Head	Column Spanner			
	Column Head	Column Head	Column Head	Column Head
Row Head	Field Spanner			
Row Head	Field Spanner			
Explanatory Note:				

more confusing than helpful to the reader, so writers should avoid including too many different sorts of information in the same table. In general, the writer may vary information by column or by row, but not by both at the same time. As another general rule, tables are a good choice when the number of data sets is twenty or less. A chart or graph is better suited for larger numbers of data sets.

### Columns and Rows

Representing the data may not require all the parts that the table above has, so only as many categories as the data require should be used. Writers should create column headings to designate dependent variables and row headings to designate independent variables or categories. For example, a table showing the relationship between biodiversity and land area might list the names of species of plants as row headings and the land sampled as columns headings. Each table cell could then contain the number of individuals of each species in a specific land sample or plot.

In general, each column heading should apply to all the members in the column and each column category should be unique. Column headings are centered if they are less than one line; longer column headings are left-justified. Columns may also use subheadings, and these will frequently be units of measurement. Such subheadings should be centered between parentheses beneath the column heading. If specific columns are referred to in the text, those columns should be numbered using arabic numerals placed between parentheses beneath the column heading or subheading.

As with column headings, row headings should be unique to their row and apply to all members of their row. They should be brief and clear; and any needed secondary information should be placed in a note, as located above. Row headings are left-justified and use standard capitalization, just as columns do. The stub head designates the row headings, and should not be left blank unless the table's title clearly identifies the rows. For example, a stub heading for the biodiversity table described above could be "Species of Plants." However, if the table's title was "Species of Wild Plants in Suburban Green Belts," the stub heading could be omitted and the graphic made more economical.

One of the virtues of a table is its relative flexibility in adding or subtracting categories. In horizontally ruled tables, column spanners can be added to show relationships among a hierarchy of columns. For example, the biodiversity table could be designed to tell how many of each species were found in suburban *and* rural plots of the same size. In that case, a column spanner, such as "Sampled Area" could be used above the two column headings, "Suburban Green Belt" and "Rural Woodland," for example, indicating that "Sampled Area" is a broader category than the two column headings.

Field spanners can be used to designate a third variable, in which case the row heading for each new field spanner is repeated, as shown above. For example, the biodiversity table could represent the species of each category, "Suburban Green Belt" and "Rural Woodland," at different altitudes, those occurring only below one mile above sea level and those occurring only above it. Using field spanners would allow the writer to add this level or category of data. Obviously, a writer would not use only one field spanner in a table.

### Placement of Data

All the data in a table, whether text or numbers, should be aligned consistently for the ease of the reader. Text is generally left-justified, while whole numbers are generally right-justified. Formulas are aligned on the equal sign. If dates and times make up part of the table, they should be represented in a consistent format: for example, either "7/10/95" or "July 10, 1995," but not both, so that they can be aligned.

Spaces in the table for which there is no data should not be left blank; an absence of value is indicated by inserting ellipses points or by using a zero; the abbreviation *N/A* and the phrase *Not applicable* are not appropriate for science writing. Instead, explain the absence in a note. Nor do science writers use ditto marks to show repeated values in a column. And for the reader's convenience, if the table consists of long columns of numbers, a blank line can be inserted every five or ten lines.

### Table Notes

The most common types of notes a table might have are those which cite sources for the data in the table and those which explain or clarify the data in the table, such as degree of accuracy, or how values were manipulated or rounded off or how the data were collected. Source notes should always be listed first, before explanatory notes, and the source citation should be preceded by "Source."

### Numbering Tables

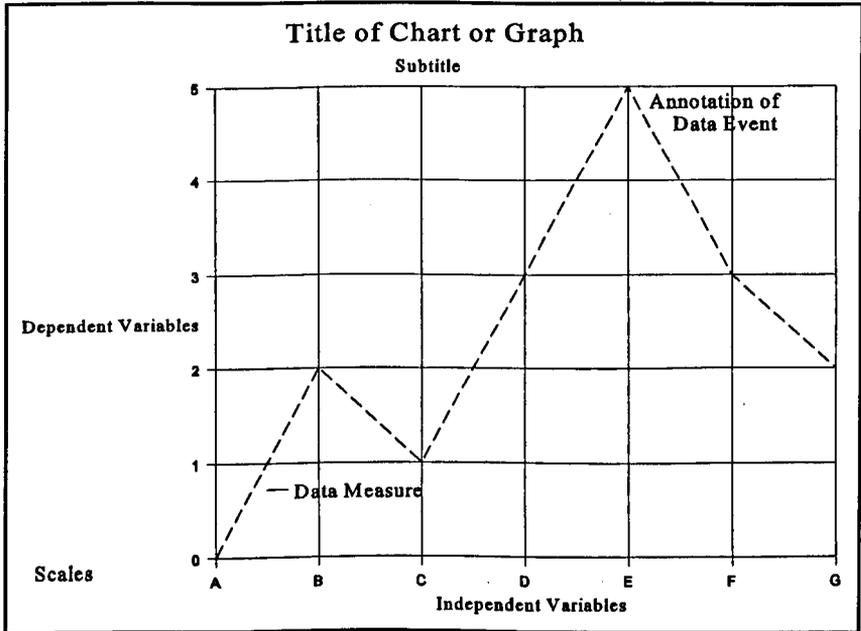
Number tables in the order they appear and cite them in the same order in the text, but do not number a table if it is the only one in the text. (Also, remember that if two or more tables are used, they should be of the same design, if possible, for a single piece of writing.)

**Exercise 3:** Starting with the various bits of information given for the "biodiversity table" examples above, and adding categories and data you invent as needed, prepare a table that has all the parts of the table depicted on p. 120.

## Charts

Charts are used for representing quantitative relationships, such as the values of numerical data, a process or change over time, or patterns of data. They are frequently used to predict future data based on data already known. Charts should be simple to apprehend, clear, and concise, and the design should not distort the data.

Parts of a Chart:



### Title and Scales

Every chart and graph should have a brief but adequately descriptive title, preceded by a figure number if needed. Scientific writers avoid humorous, partial, or obscure titles. Charts and graphs require at least two scales, one along each axis, and can be selected to show change linearly, logarithmically, or exponentially. The scale label must make clear which scale is being used.

### Data Measures

The graphical element that actually locates the data on the graphic is called the *data measure*. The data measure on charts can be represented by a variety of dots, lines, or areas. Data measures should be selected according to

whether the writer needs to represent exact values or trends. A point or dot will indicate an exact value, whereas a line would indicate a trend. It is difficult for a reader to estimate the value of or to compare areas or volumes, particularly if they are irregular in shape, so these should be avoided if possible. Bar charts, however, which do compare areas, are frequently used by science writers, but their appearance, their size, shape, and density of shading, should be consistent with the data values they represent. Science writers do not ordinarily use pie charts, and it is best to stay away from circles and spheres in general, unless your instructor gives you other directions, or unless the nature of the data makes a circle or sphere especially desirable.

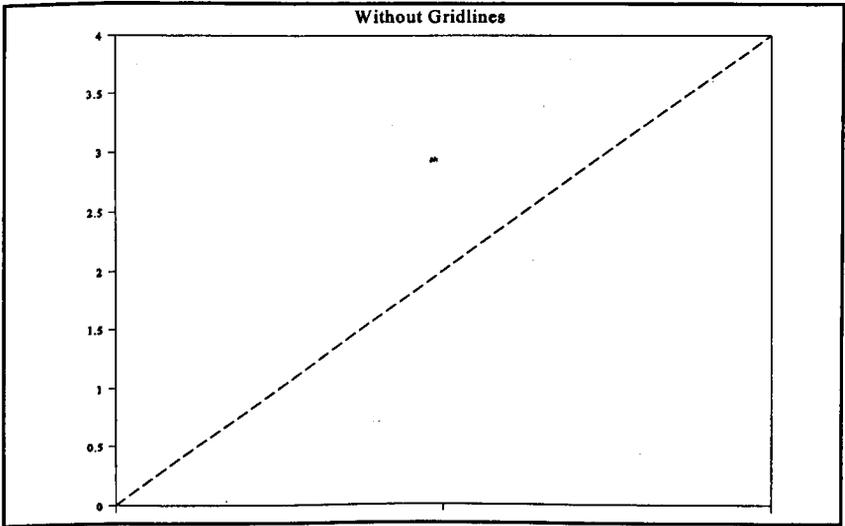
Data measures can also be represented by pictorial symbols, but science writers ordinarily avoid using them. The use of symbols should be restricted as much as possible to those symbols accepted as conventions in the area of science the writer is working in. If other symbols must be used, they should be simple geometric forms, circles, triangles, squares. Color should be used sparingly and only for emphasis. It should not be used as the only determinant of a value, nor should it be used to make critical distinctions. Also, avoid red when possible since it is the color most likely to prevent color-blind readers from reading the chart or graph accurately.

Charts and graphs are the graphic form most prone to abuse by technical effects that contribute nothing to the reader's understanding of the data, and at the same time distract the reader from the relevance of the data. Particularly if you have access to computer graphics programs, avoid elaborate shadowing techniques, extra borders, and annoying pattern selections, such as elaborate cross-hatching or stripes which seem to shimmer on the page or give other unpleasant and distracting optical effects, especially on bar graphs. Although most computers programs allow a variety of "creative" bar graph designs, grave restraint should be exercised in design selection. Try not to stack or overlap the bars on bar graphs; they should be placed next to each other. The goal is to make each value represented as visually distinct as possible and to reflect the data accurately. Therefore, elaborate pains should be taken to avoid a form of graphic representation that visually distorts or obscures the data's actual values.

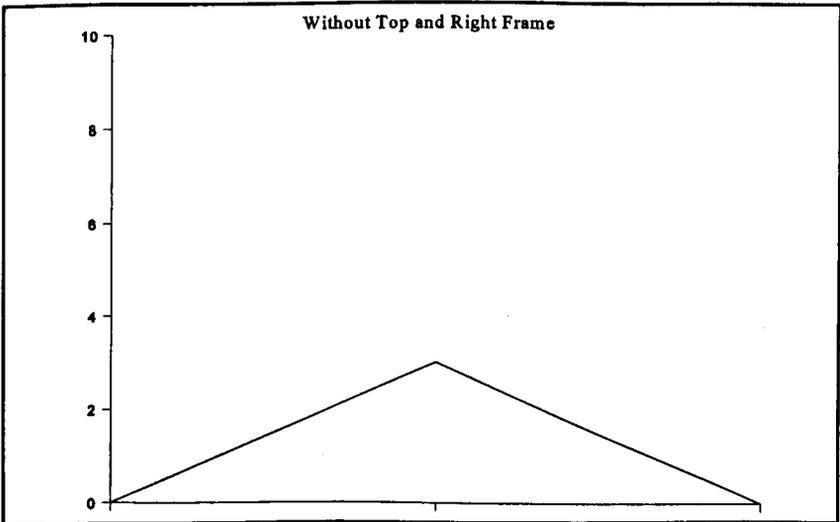
### **Gridlines and Frame**

Charts and graphs are generally framed by the perimeter of the grid on which the data values are plotted, with the gridlines usually about half the weight of the frame lines. However, it is sometimes possible to delete the grid behind the represented values altogether if the trend or pattern of the data is more significant than actual values.

The upper and right hand frame may also be omitted if the data pattern does not extend into those areas. In other words, a writer can choose to



present only the scale range that the data actually represents in order to save space.



**Exercise 4:** Here is a formula that describes the classic Malthusian account of population growth, were it to be unlimited by food scarcity or ethical constraint:  $x_{\text{next}} = rx$ , where  $x$  represents the population for the first year in which the population is measured, and  $r$  represents the rate of population growth. For example, if the rate of population growth is 1.2, then if this year's population is 10, next year's will be 12. If this year's population is 15,000, next year's population will be 18,000.

Stipulate values for  $x$  and  $r$ , and determine the population for ten years. Then draw a graph, appropriately titled and labeled (create an appropriate title and labels), to represent your data. (Will your scale be linear, logarithmic, or exponential?)

**Exercise 5:** Here's an example of a more sophisticated formula to represent population growth:  $x_{\text{next}} = rx(1 - x)$ . It is a modification of the classic Malthusian case and a variation of what population biologists refer to as a "logistic difference equation." The formula includes a variable which represents a factor which could limit population growth, such as the natural death rate and/or the additional death rate from starvation and predation. This formula expresses the largest conceivable population of the represented species as 1, and 0 would represent extinction.

Using a starting population of .02 (meaning  $x = .02$ ) and a value of 2.7 for  $r$ , generate the first thirty-five years' populations. Represent your data in a well-designed, titled, and labeled table. How will you make reading the values easier for your reader?

Now represent your data in a well-designed, titled, and labeled graph. Which form, table or graph, is more effective in showing the trend of the data? Which is more effective in showing exact values? Given your findings, do you think that the data are better expressed by a table or by a graph?

## Diagrams

Diagrams are enormously useful since they can be used to demonstrate a wide variety of relationships: spatial, such as those represented on a map; sequential, such as those represented by flowcharts; and the relationships of parts to a whole, such as the visual aids to assembling a piece of lab equipment. They can also illustrate causal, connective, dependent, and compositional relationships. Students may also find diagrams an excellent means of organizing their material to assist their own learning as they record their daily work. Such diagrams are often the "first draft" of the graphic which will ultimately illustrate the text.

Some disciplines, such as computer science, use formal diagramming conventions particular to their field. If the discipline in which you are working uses its own conventions, your instructor will introduce you to them. But diagrams are routinely used in all fields of science, for both lab journals and formal papers. In lab situations, they are often used to demonstrate the assembly and/or use of an object or the relationship of parts of a process.

Diagrams are especially useful in clarifying complex relationships, as long as the design selection accommodates the structure that it represents. For example, an appropriate diagram design to represent the structure of the United States' chain of military command would be a tree form, which

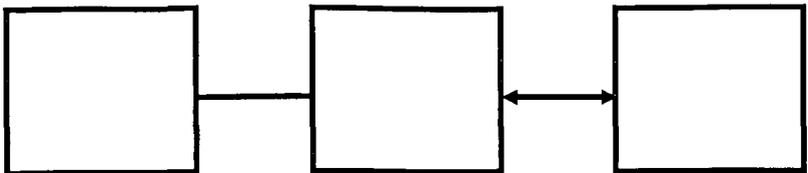
accommodates hierarchical relationships. A web diagram, however, would be appropriate to represent more complex relationships, such as chemical processes in the cell, for example.

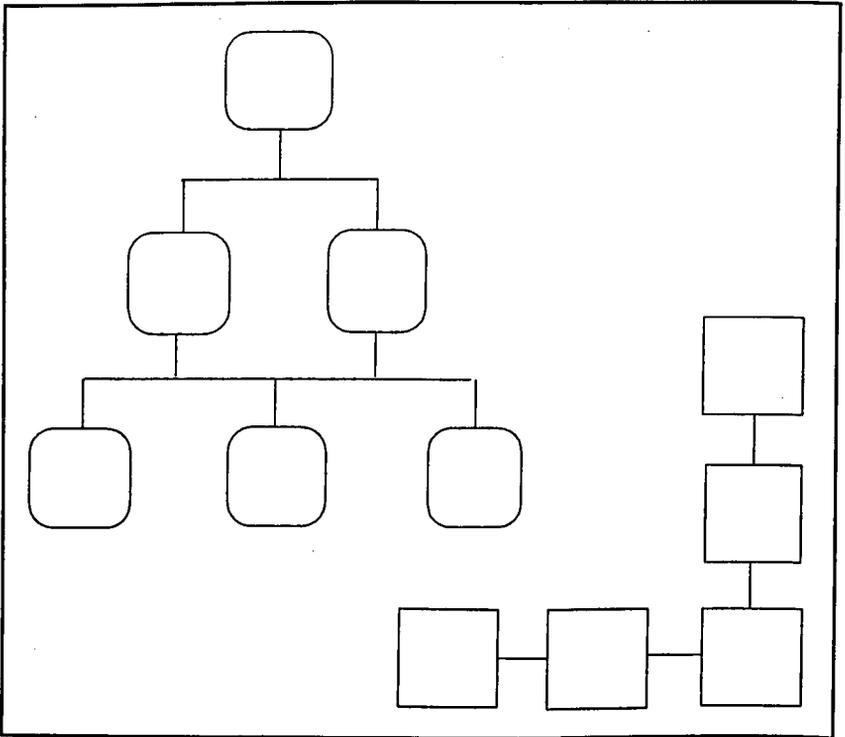
Diagrams can be composed of square or rectangular grids of various dimensions and can be designed to represent data in two logical dimensions, much as a table does. Such linear processes can be diagrammed sequentially, with connections between diagram elements indicating movement, whether forward, backward, or both, if necessary, and indicated by arrowheads on the connecting lines or arrows alongside them, if this does not interfere with clarity.

Science diagrams should use either the conventional symbols of the writer's discipline or sub-discipline, or simple geometric shapes. Larger shapes should designate the more important or controlling objects in a diagram, and a diagram should not use too many different kinds of shapes. If more than half a dozen are necessary, the writer should probably give the information in two separate diagrams. The symbols should be labeled, within the shape if possible, and immediately outside it if not. The lines linking the symbols may be labeled as well, and if space permits, may be written on the line itself; if space does not, the label may be written just above it. Whenever possible, labels should be written horizontally for the reader's convenience. As with other graphics, diagrams must have titles and numbers if the text contains more than one diagram.

Whatever the overall shape and pattern of the diagram as a whole, all the diagram elements should be connected to at least one other element. None should be left standing alone. Diagrams should also eliminate all unnecessary elements of the process or structure being depicted in order to maximize the reader's ease of comprehension. If more than one diagram accompanies a text, they should be as similar as possible in their schematic elements: lines should have the same weight, boxes the same shape, etc.

Examples of possible diagram designs and elements:





**Exercise 6:** After studying the diagram examples above, think of one process or structural relationship that each would adequately represent, adding or subtracting elements if needed. Add arrows if needed, and label the diagram elements.

**Exercise 7:** Examine the diagram on p. 156. Then, using different symbols for each form of contagion, create a diagram that demonstrates Girolamo Fracastoro's germ theory of disease (pp. 219–26).

### Line Drawing

Science writers use line drawings to show particular features or specific characteristics of a complex object. Often such drawings are designed to show the reader how something works. Line drawings can also accompany descriptions of how to assemble, install, use, or maintain something. In creating a line drawing, the writer must take the point of view of the reader in determining exactly what to illustrate. For example, if only the nucleus of the cell is the focus of the drawing, the other cell contents would not be represented. But if the cell wall is the object of focus, none of the contents of the cell would be represented.

Keep line drawings simple—they should be neat, clear, devoid of unnecessary detail, and they should be in scale, although sometimes a line drawing magnifies a specific feature if necessary for clarity. As an aid to accuracy, the writer should have access to the object to be drawn, or else a very good print, photo, or photocopied image. Drawing equipment such as rulers and protractors should be used when they can make the drawing neater and more accurate. Each illustration must be labeled clearly, using arrows where necessary to indicate assembly or direction. As with other graphics, if more than one line illustration is used, they should all have the same style, line weight, font, etc.—do not mix different kinds of illustrations.

**Exercise 8:** Examine and evaluate the line drawing of a pipet bulb on p. 141. Then prepare a drawing of a piece of equipment found in your lab.

**Photographs:** Photos are used to show readers exactly how something looks and sometimes to give evidence of authenticity and/or to document the existence of something. Photos should restrict themselves to the specific object or phenomenon as much as possible. If a specific part of the photographed object is the significant element, then whenever possible, the photograph should be taken from an angle that exposes the part most fully. If necessary, an additional photograph of the entire object can be included to allow the reader to visualize spatial relationships. Photographs which distort the object depicted should be rejected. A rule or other means of determining scale should be included in the photograph if size is of significance.

Photos should be restricted to only the necessary surrounding context; unnecessary context should be cropped from the photo. A photograph of a giant land snail ascending a rock should not have the feet of the researcher in the frame, for example.

Photographs intended to accompany a text should be of the highest quality possible, sharp, in focus, and well illuminated. It will often be useful to the reader if the quality of photos is sufficiently high to allow legible reproduced copies.

Photographs must be clearly labeled, and are sometimes accompanied by a brief identifying or explanatory text beside or beneath the photo, in addition to its caption. This text is called a *callout*. If arrows indicating significant features in the photo are necessary, a ruler should be used to draw a straight line between the callout and each significant feature.

**Exercise 9:** Evaluate the photograph of a cownose ray on p. 174 from the point of view of a scientist writing about the ray's reproductive processes. Then, using the following information, write a callout designed to accompany the photo, placing arrows between text and photo to connect specific features: Cownose rays have powerful tooth plates, composed of a series

of teeth in each jaw. They school in bays during the summer and become pelagic during the winter. They are equipped with stinging spines on the ends of their tails.

### References

Tufte, Edward R. *The Visual Display of Quantitative Information*. Graphics Press, 1983.

\_\_\_\_\_. *Envisioning Information*. Graphics Press, 1990.