Analyzing Experimental Data

The information in this chapter is a short summary of some topics that are covered in depth in the book *Students and Research* written by Cothron, Giese, and Rezba. See the end of this chapter for full information on obtaining this book. The book is an invaluable resource for any middle or high school science teacher.

SETTING UP SIMPLE DATA TABLES AND GRAPHS

Students should be encouraged to set up data tables and graphs on a computer whenever possible. This can be done by first entering data into a spreadsheet program such as Microsoft Excel.

Making simple data tables...

A simple data table can be set up in the following format. The layout for the data table is based on the variables for the experiment. The first column lists the different values or levels of the independent variable, and the remaining columns list the corresponding observed values of the dependent variable. Values for each repeated trial are listed in separate columns, and then in the last column the average value. The average value will usually be a mean value, but there are some situations where a median value or even mode value would be more appropriate. The labels for the independent and dependent variable columns should both include the measuring unit if applicable, and the table as a whole should be given a title. The example below is a data table for a simple experiment to measure the effect of the length of a pendulum string on the number of pendulum swings per minute.

THE EFFECT OF LENGTH OF PENDULUM STRING ON THE NUMBER OF SWING CYCLES PER MINUTE

Length of Pendulum String (cm)	Number of Swing Cycles per Minute			
	Trial 1	Trial 2	Trial 3	Average
30				
50				
70				
90				

Displaying data with graphs...

Displaying data from an experiment with a graph makes it easier to see trends and patterns in the data. The graph presents the data in a visual format that often brings out the significance of the data much more clearly than a data table. There is a hierarchy of ways to present results from an experiment that allows increasing levels of understanding of the meaning of the results. The lowest level is a simple qualitative description of the results using words. Quantitative data, with measurements of numerical data, allows for greater understanding. The third level of complexity in presenting results is in graphical form, and the highest level is when the results can be summarized in the form of a mathematical equation.

Depending on the exact nature of an experiment, students may need to display their data using different types of graphs. As usual, the best way to make the appropriate decision about the experiment is to base the decision on the nature of the independent and dependent variables for the experiment in question. The table below summarizes the different graphs that can be drawn in different situations.

Deciding on a Graph for Different Experiments

Independent Variable	Dependent Variable	Type of Graph
Standard Scale with Equal Intervals	Quantitative	Bar Graph or Line Graph
Examples: Temperature, Height, Weight, Volume	Qualitative	Frequency Distribution Graph
Discrete Categories	Quantitative	Bar Graph
Examples: Day of the Week, Gender, Color, Brand of Detergent	Qualitative	Frequency Distribution Graph

One advantage of drawing a line graph over a bar graph is that extra information can then be obtained from the graph. The line can be used to infer values of the dependent variable corresponding to given values of the independent variable that were not measured in the experiment. A line graph is not appropriate when the independent variable is represented by discrete categories. In these cases, intervals between categories have no significance and a bar graph is a more appropriate choice.

A frequency distribution graph is a type of bar graph. In a frequency distribution graph, there will be several bars for each value of the independent variable. The bars represent the number of counts for each possible category of the dependent variable. For example, an experiment could be carried out to record the leaf quality of plants grown with different amounts of a fertilizer. If the leaf quality is recorded using a rating scale of 1-4, the frequency distribution graph would have bars showing the number of plants with each leaf quality rating, and sets of bars would be drawn for each different level of fertilizer.

There are some important things to require of students when they draw graphs. First of all the values for the independent variable should be plotted on the horizontal x-axis and the values for the dependent variable on the vertical y-axis. Setting up numerical scales will usually be the hardest part of the graph for the student to accomplish, and you may need to help students with this. Certainly, you will need to check them carefully as they work on this. If students are drawing a graph with two numerical scales, they should usually begin the scales of both axes from zero. The reason for this is that the (0,0) data point often has real significance and should be the starting point for a line-of-best-fit. For example, if students were carrying out a simple experiment to see how the height a ball is dropped from affects the height it bounces to, they would know for certain that if the ball was dropped from zero height then it would also have zero bounce. The line graph should begin from this point. Students should be required to label their graphs clearly. This means labeling both the axes, including the measuring units when appropriate, and also writing a title for the whole graph.

When students are carrying out simple experiments and not necessarily writing a long conclusion, it is useful to ask them to finish their graph by writing one or two sentences to summarize their conclusions from the graph. These sentences can be written directly on the piece of graph paper.

Summarizing Experimental Data: Descriptive Statistics

Making summary data tables...

A simple data table shows all of the measurements collected in an experiment. It can be better to simplify the display of data by reducing the amount of information with a summary data table, especially if the experiment is a big or long one. A summary data table reduces the information by summarizing the raw data using measures of central tendency and variation. A measure of central tendency is a typical or average value for a set of data. This can be a mean, median, or mode value. A measure of variation is a measure of how consistent the data are. Simple measures of variation include range and frequency distribution. Standard deviation can also be used as a measure of variation in a sample, if this is desired when working with older students.

Whichever descriptive statistics students are using, they should see how to calculate the statistics by hand first and then by using a graphing calculator or possibly a computer. There is a standard format that can be used for summary data tables. The following table is an example of a summary data table for an experiment measuring the effect of different concentrations of a chemical on the height of plants. Ten plants were observed for each concentration of the chemical.

THE EFFECT OF DIFFERENT CONCENTRATIONS OF CHEMICAL X ON THE HEIGHT OF TOMATO PLANTS IN CENTIMETERS

Descriptive Information	Concentration of Chemical X (%)			
	0	10	20	30
Mean Height (cm)	15.3	18.1	10.5	6.0
Range	7	6	6	4
Maximum	19	20	14	8
Minimum	12	14	8	4
Number of Plants	10	10	10	10

Choosing appropriate measures of central tendency and variation...

The most appropriate measure of central tendency and of variation depends on the experiment carried out and the type of data collected.

APPROPRIATE MEASURES OF CENTRAL TENDENCY AND VARIATION

Independent Variable	Dependent Variable	Measure of Central Tendency	Measure of Variation
Standard Scale with Equal Intervals Examples: Temperature, Height, Weight, Volume	Quantitative	Mean (Sometimes Median)	Range or Standard Deviation
	Qualitative (Ordinal) Example: Rating Scale from 1 – 5	Median	Frequency Distribution
	Qualitative (Nominal) Examples: Gender, Color	Mode	Frequency Distribution
Discrete Categories Examples: Day of the Week, Gender, Color, Brand of Detergent	Quantitative	Mean (Sometimes Median)	Range or Standard Deviation
	Qualitative (Ordinal) Example: Rating Scale from 1-5	Median	Frequency Distribution
	Qualitative (Nominal) Examples: Gender, Color	Mode	Frequency Distribution

The following table is an example of a summary data table for a qualitative experiment recording the effect of different concentrations of chemical on leaf quality of plants. The leaf quality was recorded using an ordinal rating scale judging leaf quality from Quality 4 to Quality 1. Since the data are ordinal, the measure of central tendency is the median and the measure of variation is frequency distribution. These measures are displayed in the summary data table.

THE EFFECT OF VARIOUS CONCENTRATIONS OF CHEMICAL X ON LEAF QUALITY

Descriptive Information	Concentration of Chemical X (%)			
	0	10	20	30
Median	4	4	2	1
Frequency Distribution				
Quality 4	10	6	0	0
Quality 3	0	3	3	0
Quality 2	0	1	7	3
Quality 1	0	0	0	7
Number	10	10	10	10

Displaying data trends...

Summary data tables are a way to summarize experimental data using measures of central tendency and variation. Ordinary graphs can clearly display measures of central tendency such as mean values. Variation in a data sample is harder to display but various techniques do exist. For example, variation can be displayed clearly by creating stem-and-leaf plots or box-and-whisker plots. A particular advantage of this kind of plot is that they draw attention to outliers in the data. Outliers are measurement values that are greatly different from the majority of measurements.

The Virginia Mathematics SOL list line, bar, and circle graphs; stem-and-leaf plots; and box-and-whisker plots as appropriate graphical methods for displaying data (Math SOL 6.18). In general, students should be taught to make all of these different plots by hand first, and then later they can be shown how to make the plots using graphing calculators or computers.

WRITING A CONCLUSION

Six points should be addressed in a simple written conclusion for an experiment. To help make sure that students cover all of these six points, they can be asked to write a conclusion paragraph by answering six questions. This makes it a lot easier and more manageable for the students to write the conclusion by giving them a framework to follow. They can focus on each separate part of the conclusion and then move on to the next one, and not have to create the entire paragraph at once from a blank page.

The written conclusion should answer each of the following six questions.

1. What was the purpose of the experiment?
2. What were the major findings?
3. Did this support your original hypothesis?
4. How do your findings compare with other people's experiments or with the information in your textbook?
5. What explanation can you think of for the findings?
6. How could this experiment be improved or extended?

The teacher can give students further help in making their written conclusion by using examples to teach the class how to answer each question. You can work with the class on each question in turn, using the chalkboard to write answers to the question suggested by students. This will work well if several different answers are taken for each question, so that students can see that there will more than one acceptable way to write the conclusion.

ORAL PRESENTATIONS AND POSTER DISPLAYS

Making oral presentations...

Making oral presentations gives students useful practice of a number of valuable skills. Oral presentations should begin as very short and simple statements by students to their classmates. Later on the students may make more elaborate presentations in competitive events, such as the Virginia Junior Academy of Science (VJAS) competition.

An oral presentation for a competitive event, such as VJAS, should last about 10 minutes. Classroom presentations will be much shorter. A good way to start getting students used to talking about experiments and investigations is to have students in a class each take just a minute to share their proposed experiment before actually starting. It would be enough for the students to share just two things: the purpose of the experiment in terms of independent and dependent variable and the hypothesis to be tested. This is more manageable for the students than a full-length presentation, and the practice helps build up their confidence gradually. When making a more formal oral presentation of a completed experiment, the students should plan their presentation to include each of the following steps.

- Introduce yourself and say why you were interested in doing this experiment.
- Describe the problem investigated and give background information.
- State the specific purpose and hypothesis of the experiment.
- Describe the procedure that was followed. Acknowledge any help that was received from other people to carry out the experiment.
- Explain the results. This can include presentation of data tables and graphs.
- State your conclusions and the extent to which they support the original hypothesis.
- Suggest areas for future study and for improvement of the experiment.

Help students give their oral presentations by reminding them that it is normal to be nervous speaking to an audience and by reassuring them. Encourage students to talk about their experiments with enthusiasm, and take every opportunity to teach basic principles of public speaking and oral presentations. You may choose to take the opportunity to have students use a presentation computer program such as Microsoft PowerPoint. It will help students to have other people model the process of giving oral presentations. This can be done by visiting former students or students from other classes, or by the teacher demonstrating the presentation of a research paper.

Making poster displays...

A poster is a good way for students to present the results of an experiment or investigation for sharing with others. The poster board is also the standard presentation format for science fairs, the dominant competitive event at local and regional levels. The poster format should parallel the components of a simple written report: title, statement of problem, procedure (methods-material), results, and conclusion. These different components should generally be laid out on the poster board from left to right to tell the story of the experiment as the reader's eye moves across the board. Students should be creative in putting their poster displays together. The choice of colors is important in making the poster appealing to the eye. A black-colored poster board makes an attractive backdrop. One interesting idea is to encourage students to use recycled materials when setting up their posters.

On the poster board, the title may state the independent and dependent variables or, alternatively, may be creatively worded to catch the reader's interest. The statement of the problem should clearly communicate the essentials of the experiment. Typically this will include the question being investigated and the original hypothesis. Because of limited space, the procedure must be stated concisely. It can be either in list or paragraph form. The results of the experiment will often be data tables and graphs showing the findings, along with perhaps a short written summary. Whenever possible, photographs or diagrams should be included to make the results clearer and also make the poster attractive. A digital camera is invaluable here for taking photos of experiments. The conclusion should summarize the major findings and the extent to which the results support the original hypotheses, as well as an explanation of the findings. Major recommendations for additional research and improvements can be included if space permits.

Resources

- *Exploring Data*. Landwehr, J. M., & Watkins, A. E. (1994). Palo Alto, CA: Dale Seymour Publications.
- *Introductory Science Skills*. Gabel, D. (1993). Prospect Heights, IL: Waveland Press, Inc.
- *Learning from Data: An Introduction to Statistical Reasoning*. Glenberg, A. (2nd Ed.). (1996). Mahwah, NJ: Lawrence Erlbaum Associates.
- *Students and research: Practical strategies for science classrooms and competitions*. Cothron, J. H., Giese, R. N., & Rezba, R. J. (3rd Ed.). (2000). Dubuque, IA: Kendall/Hunt Publishing Company. This book provides all the information you will need about teaching K – 12 students to analyze data.