An Introductory Module and Experiments To Improve the Graphing Skills of Non-Science Majors†

Christy R. Violin1 and Brian M. Forster2*

1Environmental Science and Sustainability Program, Saint Joseph’s University, Philadelphia, PA 19131; 2College of Arts & Sciences, Saint Joseph’s University, Philadelphia, PA 19131

Graphing allows for the succinct communication of scientific data and is therefore a critical learning objective in science curricula. Unfortunately, many students, particularly non-science majors, lack the necessary skills to prepare and interpret graphs. Many students are able to interpolate data and observe general trends but demonstrate only a cursory ability to contextualize their results. In this paper, we suggest an introductory module and graphing lessons to improve the quantitative skills of non-science majors. In each of these lessons, students go through four phases of data analysis: (a) collection; (b) graphing; (c) interpolation/trend detection (reading), and (d) determining the underlying mechanism resulting in the trends they observe (interpretation). By employing these activities, we are continuing to improve the scientific literacy of students.

INTRODUCTION

Broad global data availability has had cascading effects in all areas of society (1). Data are becoming more widely available via myriad digital platforms (2). The information varies considerably in its format, quality, and source credibility (3). Given the vast amount of data available, and the ease with which it may be manipulated, misinterpreted, or misrepresented, providing students with the tools and experience to accurately discern the quality of a dataset or scientific conclusion is critical for their civic duties and professional development (4). Improving scientific literacy among nonscience majors has become a prominent goal of collegiate institutions (5, 6), often resulting in science course requirements for nonscience majors. These courses may be the only science education students receive after high school, so it is important to maximize acquisition and retention of scientific skills.

Prior to developing our introductory graphing module, we observed that students could correctly plot data points, identify independent and dependent variable(s), and describe basic correlations between the two (i.e., positive, negative). Students could only provide a cursory explanation of their results and posited little to no mechanistic explanation, despite having been presented with possibilities in both lecture and lab. Additionally, we observed that some students failed to understand whether their data were scientifically valid, especially when an experiment did not work properly. These findings are consistent with other assessments of nonscience majors (7–9). Graphing assessments of biology students and professors have been conducted previously by Angra and Gardner (10). However, they assessed biology students and professors and mainly focused on graph design. Given that graphical data analysis is a core component of scientific literacy, even for nonscience majors, we sought to develop an instructional approach to improve the graphing and interpretation skills of nonscience majors by designing an introductory graphing module.

INTRODUCTORY GRAPHING MODULE AND GRAPHING LABS

We developed an introductory graphing module for use early in the term (Appendix 1). While we created this module for laboratory use, it could also be used in a lecture setting. The module comprises three parts—introductory lecture, class activity, and group activity—and discusses experimental design, predictor and response variables, data types, and data collection methods. We address selecting an appropriate style of graph for experimental data, assigning variables to axes, consistent axis scales, and proper labeling (Fig. 1).

To teach the quantitative interpretation of experimental results, we discuss correlations, fitting linear and non-linear trends, and how to interpolate and extrapolate data. Our approach focuses on two fundamental graphing components:
describing the relationship between the independent and dependent variables and using scientific information to explain the observed pattern. Students are given a specific analysis framework that requires at least two sentences to explain their results. The first sentence describes the trend in their experimental results (e.g., “positive linear correlation”). The second sentence postulates a scientific reason and/or hypothesis for their experimental results that begins with the phrase, “This may be due to.” Students are expected to use this format when they create graphs in subsequent laboratory exercises.

Following the lecture, we work through an example as a class and create a graph jointly with students, covering all the components of appropriate graphs and conducting a thorough scientific analysis (Fig. 1, Appendix 1). Within their lab groups, students then practice graphing data sets. We provide students with a Microsoft Excel file (Appendix 3) that computes regression models and corresponding coefficients (R²). Students learn how to use R² values to choose the best-fit model.

Within our nonmajor science courses, we employ four simple experiments to teach graphing skills (Table 1). Students perform each experiment and collect their own data, giving them ownership over the process. This step helps students determine the scientific validity of their data based on how successfully the experiment was conducted. Students then graph their data, choosing an appropriate format based on data type. They then read their graph, determining the relationship between their predictor and response variables. Questions on interpolation and/or detecting trends should be posed at this stage. Finally, students interpret their graph by determining a reason for their results (Fig. 2). Since some of these activities involve the use of microorganisms, the ASM Guidelines for Biosafety in Teaching Laboratories (https://www.asm.org/Guideline/ASM-Guidelines-for-Biosafety-in-Teaching-Laboratory) should be followed.

CONCLUSIONS

Incorporating the introductory module and graphing-centric experiments into our curriculum has improved the graphing skills of our nonscience majors. We have observed anecdotally that, for nonscience majors, assigning frequent graphing assignments and providing explicit instructions for writing conclusion statements yields better results. Asking broad questions (e.g., “Explain the results of your Winogradsky column”) leads to broad answers. Students provide more detailed answers when asked a more specific question (e.g.,

![Graphing reminders](image.png)

**FIGURE 1.** Graphing reminders. This guide is presented to the students as a means to remind them to check their graphs and their interpretations before submitting them in any assignment. While most academic journals place graph titles as a figure legend beneath the graph (as shown in the figure), sometimes graph titles will appear at the top of graphs.
TABLE 1.
Graphing laboratory descriptions.

| Experiment | Brief Description | Reference |
|------------|-------------------|-----------|
| Intraspecific competition in radish monocultures | Students plant exponentially more radish seeds per pot. If intraspecific competition is occurring, students should observe a logarithmic trend in biomass. | Appendix 2 |
| Identification of phototrophic bacteria enriched in Winogradsky Columns | Students isolate bacterial pigments from different column depths for spectrophotometric analysis. Students graph their absorbance data and identify the bacterial species at different depths of the Winogradsky column. Students should determine the predominant metabolic process at each depth and correlate that with the identified organism. | (11) |
| Rate of phagocytosis in Tetrahymena pyriformis | Students add 1%, 5%, or 10% India ink to cultures of *T. pyriformis*. Over the course of 30 minutes, students will sample the culture, fix in 3% glutaraldehyde and prepare wet-mount slides to count the number of vacuoles containing India ink. | (12) |
| Determination of LC50 (the pollutant concentration lethal to 50% of a population) in Daphnia magna | Students prepare solutions of increasing concentration and add *Daphnia* to each solution. Following incubation, students quantify *Daphnia* mortality. Students’ analyses focus on the correlation between increased pollutant concentration and increased organism mortality. | (13, 14) |

FIGURE 2. Four features of all graph lessons. All graph lab lessons should include data collection, graphing the data, reading the graph, and interpreting the results. *Tetrahymena* picture is from ASM’s Microbelibrary (15).
“Explain why the location of the phototroph you identified graphically from your Winogradsky column makes sense.”

In conclusion, the exercises outlined in this study provide a robust approach for teaching non-science majors graphing skills that aid them in understanding and interpreting quantitative data, a critical skill in many careers. To maintain student engagement, we suggest teachers fine tune their approach to emphasize concepts their students find difficult. Our findings suggest that these include graph labeling and interpretation, and that an introductory graphing module yields immediate improvement.

SUPPLEMENTAL MATERIALS

Appendix 1: Introductory graphing module
Appendix 2: Intraspecific plant competition experiment
Appendix 3: Microsoft Excel trend calculator

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