Research, Writing, and the Computer in Introductory Biology

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The most difficult task facing an introductory biology teacher is to teach creative thinking and hypothesis testing. This task is most often relegated to the laboratory, where students carry out laboratory exercises and write laboratory reports. These activities, however, rarely teach how a scientist works. Laboratory exercises are useful for teaching techniques, but they are not flexible enough to encourage hypothesis testing. Because laboratory reports are artificially structured for ease of grading, they do not allow a student to see what technical writing is really like.

By combining the computer, the library, and the laboratory, the biology instructor can assign research projects requiring creative thinking and hypothesis testing. This approach is currently in use in Introductory Biology at Indiana University at Kokomo. The computer can provide data from experiments which are too expensive, too dangerous, or too time-consuming to be carried out in the laboratory. For example, an experiment dealing with total plant energy budget and photosynthesis would be too expensive; one dealing with disease-causing pathogens would be too dangerous; and one dealing with a multiple site ecological study would be too time-consuming. The data required by these experiments could be provided quite easily using the computer. The library can provide the background information required by the students to understand the experiment. Pertinent references could be placed on reserve or the students could be taught to carry out a literature search using biological source materials. The techniques required to collect the data can be illustrated by actual laboratory exercises or by slides or films to give the students some idea of what type of work the computer program is doing for them. Finally, the science report prepared at the end of the assignment can be used to teach the students how an actual paper is prepared without the artificiality of being a laboratory report.

A computer-based research project provides a very valuable learning experience for both majors and nonmajors. Their experience with this project is the most important concept they can take away from an introductory course. After working on an actual research project, the nonmajors should feel more secure about the accuracy and objectivity of scientific reports. Majors can use this experience to decide whether or not they would like to perform this type of work for the rest of their lives.

The Model

I chose an ecological model as the basis of the research paper. Plant ecologists (9) and paleobotanists (2,3,11) have postulated that a close relationship exists between leaf form (either leaf margin type or leaf size) and climate (mean annual temperature or average annual precipitation). Bailey and Sinnott (2,3) showed that the percentage of woody dicot species having leaves with entire margins (neither toothed or lobed) decreased with decreasing mean annual temperature either altitudinally or latitudinally. Their conclusions have been supported by more recent work by Wolfe (11). The relationship between leaf size and climate is less clear. Raunkiaer (9) postulated that leaf size in the woody dicots should decrease with decreasing average annual precipitation either altitudinally or latitudinally. In contrast, Givnish (7) predicts that average leaf size should be highest in the tropics, decrease into the subtropics, increase once more into the temperate zone, and finally decrease toward the poles. These theories provide an excellent basis for a research project. Sufficient disagreement exists between workers in the field such that no certain answers are available in the literature. Each theory deals in a general way with the variation of leaf form with climate. Only one detailed study has been carried out over a small area (6). Therefore, a locally relevant project could be developed, if the students studied the climate and flora of their State.

Three simulations are available enabling my students to study the variation in leaf form and climate in Indiana: CLIMATE, LFMARG (LeaF MARGin), and LFSIZE (LeaF SIZE). CLIMATE provides weather data from 91 weather stations in Indiana and the surrounding states of Michigan, Ohio, Kentucky, and Illinois. Seven climatic parameters may be studied: mean annual temperature, mean annual range in temperature, average annual precipitation, mean annual biotemperature (8), potential evapotranspiration ratio (8), effective temperature (1), and equability (1). Climatic data may be requested for a specific series of months (for example, May to October, the growing season in most of Indiana) or for the whole year. LFMARG calculates the percentage of species having leaves with entire margins for any county in Indiana. LFSIZE calculates either the average leaf area (7) or a seven-class leaf size distribution (9) for any county in Indiana. LFMARG and LFSIZE calculate answers using either the total number of woody dicotyledonous species found in a county or some subset of this information. An analysis of the total woody dicotyledonous vegetation may be subdivided into trees, shrubs, or vines based on growth form or into deciduous or evergreen species based on plant habit. Therefore, a student might study the variation of only the evergreen trees of Indiana.

These three simulations are built around two large data bases. CLIMATE queries a data base built using climatic data provided by the U.S. Department of Commerce (10). Their report gives the average temperature (°F) and the average precipitation (inches) by weather station for each month of the year. After being converted to the metric system, these data may be used directly, or they may be used to calculate a climatic index, such as mean annual biotemperature. LFMARG and LFSIZE query a data base containing information on each of the 227 woody dicots native to Indiana. The data bank records the name of each species, its leaf characteristics (both margin type as well as the range in leaf length and width), its growth form (tree, shrub, or vine), its growth habit (deciduous or evergreen), and the counties in Indiana in which it grows.

The Assignment

The students have approximately ten weeks to complete their research projects. Two weeks after the start of the semester, the students are shown the University's computer facilities and are introduced to CLIMATE. Initially, the students use CLIMATE to obtain information to map the variation in mean annual temperature and average annual precipitation over Indiana. They may not collect data from all 91 weather stations. They may request information for a total of 30 weather stations, but they are asked to collect the data slowly while reflecting on where they should sample in order to gain an accurate picture of how the climatic variable being studied fluctuates across Indiana. After they start analyzing the variation in leaf form, they may return to CLIMATE to study other climatic variables or to study the effect of temperature and precipitation over a portion of the year. At the end of two weeks, the students must turn in their contour maps for the first two environmental variables. The maps are not graded, but the students are told where corrections should be made.

At the same time as the students are starting their computer projects, the basic principles of ecology are being covered in lecture. In addition, the students spend two weeks identifying the woody plants on campus in the laboratory. After learning how to identify these plants, they analyze a forest stand to identify the most important species. At the end of the first five weeks of class, the students have lecture, laboratory, and computer experience with their projects.

Once their climatic maps have been completed, the students are ready to start studying the variation in leaf form in Indiana. However, except for some background material that has been presented in lecture, they do not know what to expect. To obtain background information, the students must go to the library and answer a number of questions which I provide. For example, a student studying the variation in leaf margin must answer the following questions:

1. Who were the first researchers to study the relationship between leaf margin type and environment?
2. What did the first researchers conclude?
3. What other researchers have studied this relationship?
4. Some researchers feel there is a close relationship between leaf margin type and environment. How close?
5. Does anyone oppose these views? Who? What does he/she believe?
6. You will be studying the variation in leaf margin type and climate at the local level in Indiana. In what other states has this relationship been studied? What conclusions were reached relative to the subset of the vegetation of Indiana you might be studying?

The articles needed to answer these questions (2-7,9,11) are on reserve in the library. By answering these questions, the students collect the information necessary to write the Introduction of their research report. Two weeks after the readings are assigned, the Introduction must be turned in. The Introductions are then passed out in class, and the students criticize their own writing.

The students use their Introductions to reserve the type of leaf variation they would like to study. One student might choose to study the variation in average leaf size for the total woody dicotyledonous flora of Indiana. Another student might wish to analyze the leaf margin variation in only the deciduous shrubs. After choosing their projects, the students are introduced to the simulations, LFMARG and LFSIZE, which will provide them with information about their projects. The students will analyze the vegetation in only 30 out of the 92 counties in Indiana. Only a portion of the counties in Indiana may be studied because complete sampling is impossible in an actual field study due to time and financial constraints. If a student is particularly insistent, he/she may analyze more than 30 counties. This student is warned that simply adding more data does not necessarily make it easier to arrive at valid conclusions. After finishing their analyses, the students, on a map of Indiana, contour the variation encountered. As with the climatic maps, the vegetation maps must be turned in for approval.

The students reach conclusions by comparing the variation on their climatic maps with that on their vegetation maps and noting any trends. An interesting feature of the simulation is that the general theories relating leaf form with climate are not necessarily accurate at the local level in Indiana. For example, leaf margin variation for the dicotyledonous tree species conforms fairly well to the variation in mean annual temperature, but leaf margin variation in the woody shrub species does not. Because the results they find do not always fit the theories in the literature, the students must give careful consideration to the conclusions they draw in their final reports.

The final report must be written in the format of a scientific journal. The report must contain the following sections and answer the following questions:

1. Title	What was the experiment about?
2. Introduction	What work has been done on this topic? How is your project related to this work?
3. Materials and Methods	How was the project carried out?
4. Results	What did you discover?
5. Conclusions	Do your results confirm or refute what other researchers have said?
6. Literature Cited	What references did you use?

Only after the final report has been turned in is the student's project graded. Two points need to be mentioned about how the project is graded. First, although the conclusions are important, their grade is not based upon obtaining the "correct" answer. The lack of emphasis on a "correct" conclusion is a reflection both of the complexity of the project and of a student's ability to argue in favor of some plausible conclusion. Second, considerable emphasis is placed on how well the report is written, reflecting the need to have science reports graded for grammar and style.

Conclusions

Nonmajors as well as majors taking a course in science should come away from that course with some understanding of how a scientist in that discipline functions. Neither the lecture nor the laboratory provides this experience. The computer-based research project described in this paper does. By combining the lecture, the laboratory, the library, and the computer, this project illustrates the steps in the scientific method and how an individual scientist struggles to apply them to his or her research. In addition, the project does not neglect technical writing, the method by which the information generated reaches the scientific community.

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