Chapter 11

Science as Investigation: A First Majors Course Teaching the Process

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Introduction to Course Design

As Sagan (1980) noted, science is much more a way of thinking than it is a body of knowledge. Unfortunately, even after several high school science courses, as Fogle (1985) has pointed out, introductory college students do not generally understand the nature of scientific questioning or such terms as hypothesis, fact, and theory.

Furthermore, as the National Advisory Group of Sigma Xi (1989) noted in their 1989 report on undergraduate education in science, mathematics, and engineering, college science generally fails to solve this lack of understanding. With their emphasis on science as a body of knowledge, college curricula fail to remedy the problem, placing little or no emphasis on the process of investigation. The Advisory Group urged, by contrast, the inclusion of process-oriented introductory laboratory courses, and a research experience for all science majors.

As Leonard (1989) has observed, over the last 10 years, an increasing number of innovative programs have been developed in college laboratory teaching, many of which incorporate some variant on the “inquiry” theme. However, since science *is* inquiry it seems strange to this author that inquiry is such a recent and still uncommon teaching style.

The introductory majors biology course at Southeast Missouri State University earns three credits. It is divided into a lecture/discussion component dealing with scientific thinking and the major biological principles, and the laboratory component which is the focus of this chapter. The laboratory objectives include no specific biological content; rather, objectives are limited to outcomes relating to the scope, limitations, and process of scientific investigation.

In developing both this course and a related non-majors laboratory course with similar objectives, it was first necessary to recognize student limitations. It was also necessary to acknowledge that our objectives would be difficult for introductory students to achieve. Typical of such students nationally, in the sense identified by Piaget's model of cognitive development (Inhelder and Piaget, 1958) only some 25% of our incoming freshmen are formal operational thinkers. In order to promote in concrete operational and transitional students the development of an understanding of experimental design, it is necessary to break the process down to relevant concepts and component skills, and deal with each extensively, placing it into as familiar a context as possible.

Furthermore, applying Bloom's taxonomy (Bloom, 1956) to the learning objectives in such a course reveals clearly that many are at the higher end: evaluation, synthesis, and analysis. In order to promote achievement of such objectives, it is necessary to lead students sequentially through the lower objectives (memorization, comprehension, and application) as applied to each of the related concepts and component skills.

The laboratory is scheduled to meet once a week for 2 hours during a 16-week semester. It comprises six laboratory activities. Students use the laboratory manual extracted and summarized here (copies available from the author), with assignments from Ambrose and Ambrose (1987). Class sessions are primarily discussions and group exercises. Class and group discussions are based on assigned preparations from the manual that include study guide questions. Informal and formal writing are important student activities throughout the course. Most class activities are conducted in groups of four students.

What follows is a brief outline of the activities in the course including some specific assignments that focus on particular skills.

Laboratory 1: Epistemology and the Nature of Science

Introduction *(Two class periods)*

This exercises is designed firstly to challenge students to think about what they know and how they know it. It includes a discussion of the use/misuse of such terms as fact, truth, and reality which allows students to see that what we think of as certainty represents only greater degrees of probability determined as a result of weighing the evidence for competing ideas. Combined with exercises on the formation and evaluation of everyday opinions, and the general goals and practice of science, this allows the process of scientific reasoning to be placed into a broader and personal context for each student.

Materials: None—besides readings.

Notes for the Instructor

Steps 1.1–1.5 are completed in pairs, with students asking one another the questions. Representatives responses to 1.1 and 1.2 are collected on the board.

Students are also asked to develop categories separately for both the class and their own answers to each of questions 1.1 and 1.2. From this, an understanding of Figure 11.1 is developed. This is followed by class discussion of the listed terms revealing how confused are their everyday meanings. The limitation of our perceptions and the barrier this leaves between perceptions and the “reality” we seek to measure reveals why we cannot offer scientific “proof” nor claim science seeks “truth.” Through this discussion students discover the importance of evaluating evidence and falsifying hypotheses in our search for understanding.

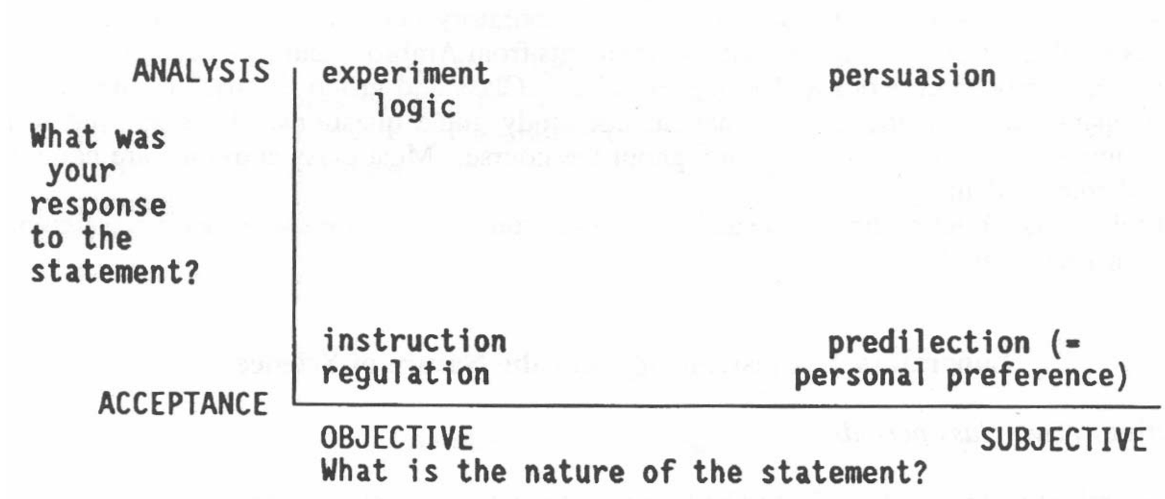

Figure 11.1. A graph illustrating possible means by which we explore our Universe.

Questions 1.6 to 1.9 follow from Figure 11.1 illustrating the means by which we formulate and evaluate our own opinions. The role of evaluating evidence is introduced together with the importance of daring to have a "wrong" opinion while being prepared to change an opinion in the face of overwhelming contradictory evidence.

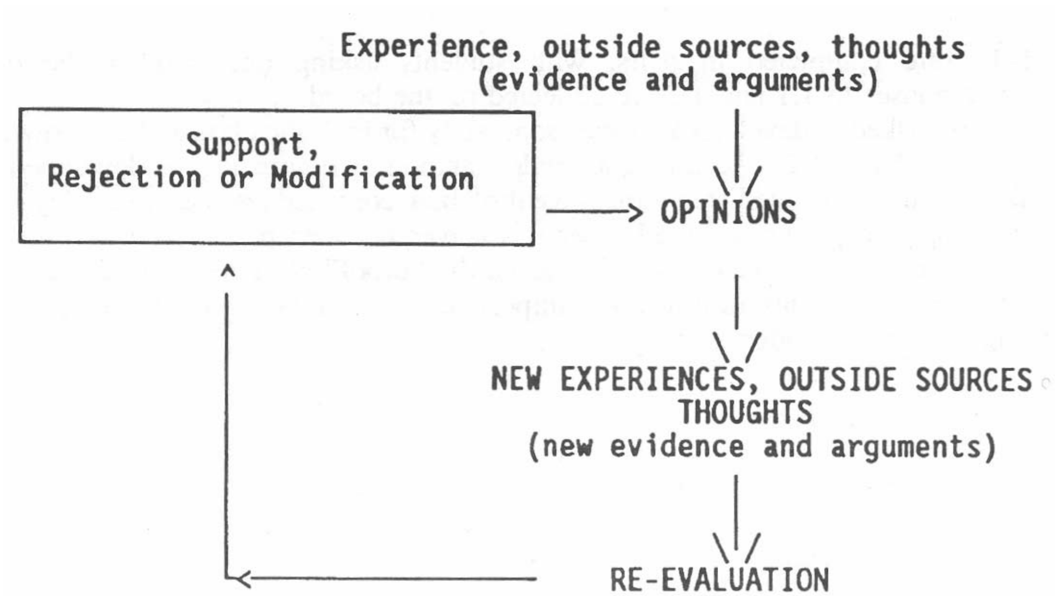

Figure 11.2. The generation and examination of opinions.

The discussion of 1.9 introduces the importance of Type I and Type II errors in a scientific world without certainty. Figure 11.3, dealing with the CFC-Ozone connection, illustrates this essential scientific dilemma.

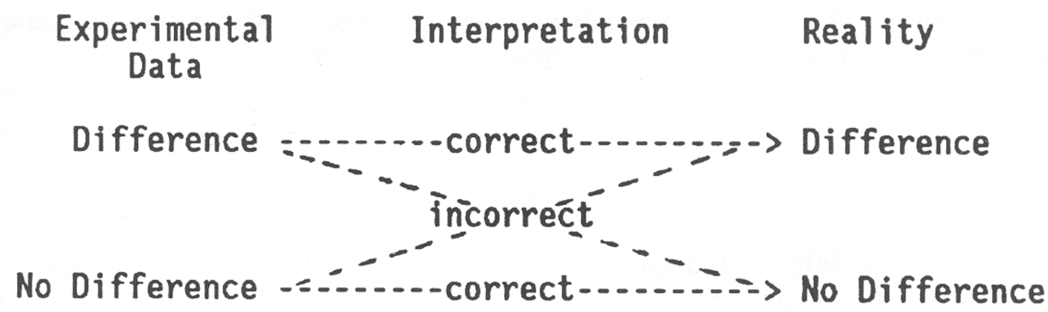

Figure 11.3. Errors in the interpretation of results.

Questions 1.10–1.12 use the opinion cycle to promote a close reading of a text on the nature of science, to promote identification of the views presented, and focus these with a personal statement. Questions 1.13 provides a preview to the next class exercise on hypothesis development and testing.

Student Outline

1.1 Identify five things you know and three things you think are true.
1.2 Identify how you came to know or think each of these.
1.3 Rank these statements in order of certainty.
1.4 Define the terms “fact,” “truth,” and “reality.”
1.5 Identify each statement in 1.1 as “fact,” “truth,” or “reality.”
1.6 Identify your views on the assigned environmental issue and justify these views—then read the assignment.
1.7 Identify your new view and justify it.
1.8 How do scientists decide about such issues?
1.9 Given the choice between claiming there *is* an environmental threat when there is none, and claiming there is *no* threat when there is, which would you rather make and why?
1.10 What is science? Reading of extracts from Chapter 2 of Sagan's *Broca's Brain* (Sagan, 1980).
1.11 Identify the idea presented by Sagan (1980).
1.12 In your own words, what is science?
1.13 A series of questions on the nature of hypotheses, where they come from and what we do with them.

Laboratory 2: Observation, Generalization, Hypothesis, Prediction, and Test

Introduction *(Two class periods)*

These laboratory exercises are designed to introduce some basic components of the process of investigation, including: observation, generalization and inference, the nature of variables and relationships, graphing techniques, hypothesis, prediction, and testing.

Materials: None

Notes for the Instructor

Through a series of definitions and application questions the concepts of observation (as a single specific perceived event) and generalization (a pattern or regularity from among a set of observations whether descriptive or explanatory) are introduced. The terms precision and accuracy, quantitative and qualitative, objective and subjective are differentiated.

The difference between observation and inference is introduced through a short three sentence story that illustrates the need for evidence in our search to discriminate among possible explanatory inferences:

> "It was 10:30. Pat has asked me to be home by 8:00. When I walked through the door, Pat was sitting on the couch with a bright red face."

Through an exercise on observing books from the students' own collections, identifying patterns, and then intuiting possible generalizations, the use of intuitive as opposed to inductive reasoning in determining the boundaries for generalizations and hypotheses is also introduced. The model presented in Figure 11.4 is employed in this discussion.

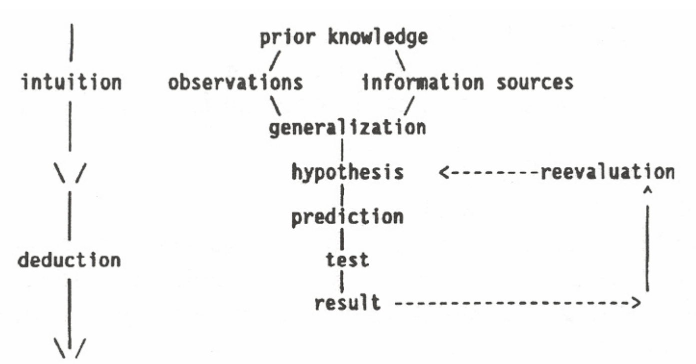

Figure 11.4. Initial model of scientific investigation.

The concept of a hypothesis as a clearly and carefully defined descriptive or explanatory predictive statement derived from the generalization is discussed with reference to the same example. The prediction is defined as a logical and testable consequence of the hypothesis. We discuss a standard student definition of the hypothesis as an "if-then" statement. I do not require that hypotheses be stated this way, and point out that this should be more correctly described as an "if-if-then" series, where the first "if" refers to the hypothesis, and the "if-then" sequence actually refers to the prediction.

With reference to a discussion of the relationship between water temperature and the time it takes ice cubes to melt, variables, relationships, and the need to identify all possible outcomes of an experiment before testing hypotheses are introduced. Graphing is introduced with reference to this example and the distribution of students among sections of the course when the difference between line and bar (frequency histogram) graphs is illustrated.

Graphing techniques are developed further with reference to data supplied by the students (height, weight, foot size, gender, age, pulse rate resting/30 seconds jogging/60 seconds jogging). The principle of the graph as a rhetorical devise to illustrate a generalization is discussed. This exercise also reviews the entire observation-generalization-hypothesis-prediction-test sequence.

The notion of variability among replicates is introduced with an exercise in which students measure a series of pine needles, calculate means of the increasing sample, and plot the means on a graph. This illustrates that the means initially change dramatically as sample size increases, but eventually stabilize. This identifies the sample size necessary to obtain a reasonable representation of variability in the population.

Laboratory 3: Hypotheses and Proof in Science

Introduction *(Three class periods)*

From this laboratory onwards a complete model of the process of scientific investigation is introduced as an expansion of that presented earlier with the **research hypothesis** replacing the hypothesis, and the **experimental null hypothesis** and **experimental alternate hypothesis** inserted between prediction and test (Table 11.1). In the next laboratory, **statistical analysis** of results is introduced.

Table 11.1. The expanded model of scientific investigation.

1 prior knowledge, experience, and interest
2 observations and information sources
3 generalization
4 research hypothesis
5 prediction
6 experiment
7 experimental null hypothesis
8 experimental alternate hypothesis
9. analysis of results
10. re-evaluation

During the laboratory students cycle through the sequence three times on studies relating to heart rate/blood pressure and exercise, and once with an example from their everyday lives. The structure provides students initially with a model involving pulse rate and exercise, and then encourages increasing diversity and independence from this model.

Materials: Stethoscopes and sphygmomanometers, one set per pair of students.

Notes for the Instructor

Step 3.1 uses text information, personal observations, and the class data compiled earlier to develop a generalization. Step 3.2 requires a statement of what students think and what animals they include within the universe. In steps 3.3 and 3.4 the research hypothesis and prediction are defined.

Step 3.5 is difficult for students. Many simply wish to have some people exercise and measure the before and after pulse rate. Others will include a resting control, but then completely fail to identify its function correctly in the null and alternate hypotheses. Thus, they will often say "pulse rate in the experimental group will rise while that in the control will stay the same" as the alternate hypothesis. Then, in analyzing possible results, they will say that if both the experimental and control pulse rates rise, but the experimental rises more, the null hypothesis is supported. Or, if the experimental remains the same and the control drops, they will conclude incorrectly that their expected alternate hypothesis is falsified. Students have only a vague sense of controls, but they almost universally misinterpret these proposed possible results. This discussion underlines the importance of stating experimental null and alternate hypotheses that clearly include all possible outcomes, and allow the appropriate interpretation in each and every case.

The relationship between research hypotheses and expected experimental outcomes is illustrated in Figure 11.5.

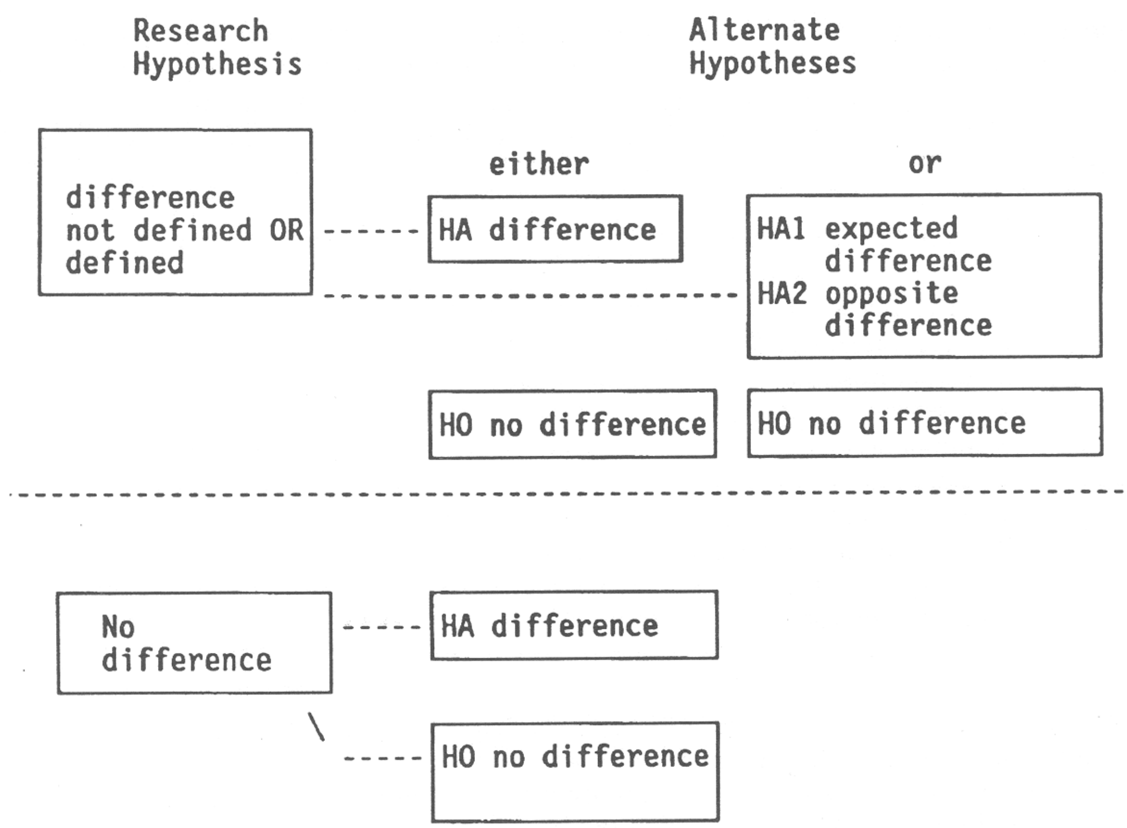

Figure 11.5. Relationship between research hypotheses and experimental null and alternate hypotheses.

In step 3.6 data interpretation in relation to experimental hypotheses and the research hypotheses is discussed from several data sets indicating different patterns. Steps 3.7 involves a review of the story about the broken television reveals that we can get the "right" or expected result from a test when the reason, our hypothesis, is totally false; this is another illustration of why there is no proof in science. Thus, if the test result is as predicted then the research hypothesis *may* be true or false, while if the test result is not as predicted, then the research hypothesis *must* be false.

In step 3.8 the logic of falsification is discussed with a biological analogy of the Wason-Four-Card problem (Wason and Johnson-Laird, 1972). This illustrates the crucial role of seeking falsification rather than seeking support in the conduct of scientific research. Only Marathon and Rifle are capable of falsifying the hypothesis, and they can support it; at best Bryce and Flagstaff can support it, at worst they offer no information.

The remainder of the laboratory involves students in repeating this exercise with a different prediction from the same hypothesis. They then develop their own research hypotheses about the relationship between blood pressure and exercise. A prediction is generated and a test designed. This hypothesis is tested by the entire class, the data are collected, and an interpretation required.

Finally, students develop the sequence again, but with reference to examples from their daily lives. Throughout this exercise application of the ideas to new situations forces students to test their understanding of the principles being developed.

Student Outline

3.1 Identify any observations and information you have on pulse rate and exercise.

3.2 Identify a reasonable generalization about this relationship, identify and justify a universe. Model: As physical activity increases, pulse rate increases.

3.3 From this generalization define a simple testable predictive research hypothesis. Model: Individuals (what people?) who are subjected to physical activity (how defined?) will exhibit an increase in pulse rate.

3.4 From the research hypothesis identify a prediction. Model: If we subject a random sample of 18–25 year old Americans to 30 seconds of push-ups their pulse rate will increase.

3.5 Describe an experiment including the experimental null (HO) and alternate (HA) hypotheses. Models:

HA_1: The 15 students measured before and after 30 seconds of exercise in the University Center will show a more positive change in pulse rate than the 15 students who rest for the same period of time.

HA_2: The 15 students measured before and after 30 seconds of exercise in the University Center will show a more negative change in pulse rate than the 15 students who rest for the same period of time.

HO: The 15 students measured before and after 30 seconds of exercise in the University Center will show no difference in change in pulse rate from the 15 students who rest for the same period of time.

3.6 Students are presented with several data sets illustrating the range of possible outcomes, and are required to interpret them, using in this case the means as the basis for judgment.

3.7 A short story is presented about arriving home to a television that fails to work, inferring the reason is a loose connection, fixing the television and finding the television works only to discover the real reason was a broken fuse being concurrently fixed by a relative. This further illustrates why proof is not a result of scientific studies.

3.8 Science is the falsification of hypotheses. The hypothesis, “Gribblegrubs occur only in Texas,” is presented along with the following information:

(a) Gribblegrubs occur in Marathon, Texas.
(b) Bryce, Utah, is a desert.
(c) Flagstaff, Arizona, has no gribblegrubs.
(d) Rifle, Colorado, is not a desert.

Which two locations will you visit and why? Complete Figure 11.6 to assist this analysis.

Location:	Marathon		Bryce		Flagstaff		Rifle	
Possible outcome:	des	no des	gribs	no gribs	des	no des	gribs	no gribs
Meaning: Falsify								
Support								
No Info								

Figure 11.6. Possible outcomes and their meaning for the gribblegrub problem.

Laboratory 4: Hypothesis Testing, Statistics, and Reports

Introduction *(Three class periods)*

Throughout the course student reading assignments and class discussion review study questions from Ambrose and Ambrose (1987). This text develops ideas about experimental design, graphing, data analysis, and the normal distribution that parallel the laboratory manual.

The assignment for Laboratory 4 involves Ambrose and Ambrose (1987) readings and laboratory manual study questions dealing with the use of statistics to determine the probability that apparent experimental patterns in data represent differences in the “real” world. These questions are first addressed in relation to the frequency distributions of the data generated by the class from the blood pressure and exercise study. The remainder of the laboratory focuses on the use of statistics to decide scientific probabilities, and the development, testing, and reporting of a study on paper towel quality.

Notes for the Instructor

The laboratory begins with a review of the use of statistical analysis to describe populations and an introduction to the use of statistics to test hypotheses (including reference to Ambrose and Ambrose, 1987). Figure 11.7 is used to illustrate the role and need for statistical analysis.

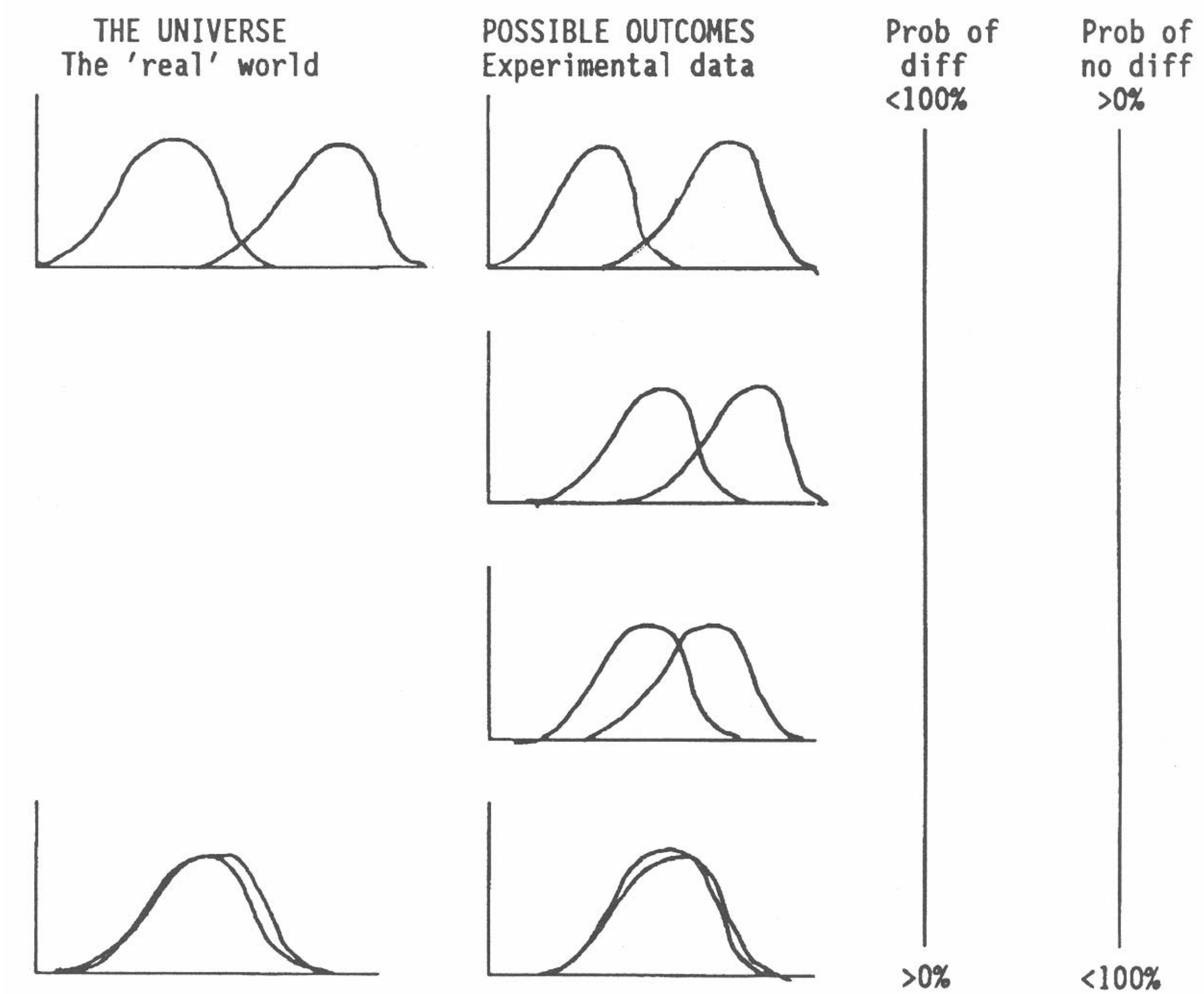

Figure 11.7. Frequency histograms illustrating the relationship between possible test data patterns and the "real" world.

This figure is used to illustrate the fundamental scientific problem of deciding which Universe experimental data most likely represent. Extreme results are easy, but with intermediate results decisions are not as easy.

Statistical analysis is introduced as a means of deciding the probability we can attach to any experimental data set representing the Universe of "no difference." Through this discussion, the dangers of Type I and Type II errors become clear. With reference to examples of various scientific problems it is possible to see that no arbitrary rule is inviolate; scientists cannot escape the responsibility of deciding the costs of Type I versus Type II errors for every experimental conclusion they draw.

This discussion reveals to students further cause to doubt the existence of "proof." Again they see science as a search through improbable and falsified hypotheses as we stutter towards those that can stand the test of time and experiment.

The discussion of statistical theory is then followed by a simple application: student groups are required to develop a hypothesis about the relationship between water and paper towels. This hypothesis they must justify, and will test.

The first assignment is to identify observations, develop a generalization, and refine this into a testable operational research hypothesis. Class discussion of the individual student hypotheses collected on the board focuses on the question of quality. Students are required to rank the hypotheses from high to low quality and identify the criteria they use. No guidance is provided; they must generate their own criteria from prior discussion and imagination. Initially, they tend to rank trivial or obvious hypotheses highly (students still have a need to be "right"). Discussion, however, produces a set of workable criteria (overlapping) mostly generated from the students: testable (falsifiable), objective, measurable, predictive, unknown/uncertain (to the experimenter), reasonable (based on some evidence or argument), clearly and precisely defined, non-trivial, defined universe, useful (sometimes included, but usually defined as synonymously with interesting to the experimenter).

Re-evaluation and re-ranking of the class hypotheses follows, with each group then being required to design and conduct a test of the top ranking hypothesis. This is usually about paper towel thickness or cost and water absorbency. Statistical analysis is required as a component of the experimental design. Both an appendix to the laboratory manual and Ambrose and Ambrose (1987) provide guidelines for the report and abstract that are required for this exercise.

Materials: Abundant paper towels of several brands, beakers, graduated cylinders and water.

Student Outline

4.1 Identify any observations and other information that you have about the relationship between paper towels and water.
4.2 Identify a generalization that these observations suggest.
4.3 Identify a research hypothesis (HR) that can be derived from this generalization. At this point we engage in class discussion of research hypothesis quality.
4.4 From the selected research hypothesis, identify a prediction.
4.5 Design an experiment to test the prediction, identifying the null hypothesis and alternate hypothesis.
4.6 What statistical analysis will you use? What limitations does it impose on the design?
4.7 How many treatments will you have? Why?
4.8 How many replicates per treatment? Why?
4.9 What will you manipulate, and what will respond?
4.10 What variables will be held constant?
4.11 Should you use a lot of paper or a little? Why?
4.12 Should you use a lot of water or little? Why?
4.13 Suppose your results are consistent with HA_1, what other explanation might there be than the one you are testing?
4.14 Does your experiment give you every chance of detecting a pattern if there is one? Explain.
4.15 Does your experiment give you every chance of falsifying a hypothesis that is wrong? Explain.

4.16 Record and analyze your results using an appropriate statistical test. Identify the meaning of your results for your HO, HAs, and HR.
4.17 What possible flaws can you detect in the design and conduct of the experiment, and how would you correct them?
4.18 Write a complete report and abstract on the research project.

Laboratory 5: Quality and Subjectivity in Science

Introduction *(One class period)*

The main purpose of this laboratory is to pause for a moment after they have experienced the process of science to discuss how to evaluate and interpret reports of science.

Three activities are used to address this objective. Firstly, student groups review a simple published scientific paper and evaluate it in relation to our report writing hints and guidelines. This focuses their attention, sentence by sentence, on what each section of the report is doing. In particular, since the main student weaknesses in reports are in the introduction and discussion, we evaluate these word by word.

Secondly, students exchange reports/abstracts and again in relation to the guidelines, students comment on the work of their colleagues and make constructive suggestions. This is preceded by admonitions about trust and how serious and valuable this process is to a writer.

Finally, students read a newspaper article purporting to represent scientific studies and evaluate and criticize the science. To underline the role of subjectivity in scientific investigation, students are required to read (for a final examination question) a paper on subjectivity in science and the parallels between scientific and humanistic thinking (Journet, 1988).

Laboratory 6: Independent Group Research

Introduction *(Throughout the course)*

This is the major objective of the course. In groups, students are required to develop a research hypothesis, design and conduct a test, statistically evaluate the data, and finally write and present a report on the project. We do not provide hypotheses, nor do we design the experiments; the hard part of science so rarely included in science classes, that of finding a research hypothesis, is an essential component of the process.

Throughout the course student groups are developing their research ideas using the principles discussed during class periods. The culmination of this is the last few weeks of the course when the class does not meet, but groups are working on their projects.

This exercise requires the understanding and cooperation of faculty in the department since, during project development, and sometimes project conduct, students require assistance and expertise that the primary instructors are unable to offer. Fortunately, faculty in the Department of Biology at Southeast Missouri State University are sufficiently committed to the notion of science as a process of investigation that cooperation has been excellent.

Materials: None—specifically.

Student Outline *(From fall 1990 schedule)*

For most of this course you will be working in groups of three or four students on *your own* scientific investigation. This activity will be worth at least 35% of your final course grade (there is an additional 5% bonus for students working effectively and diligently as members of their group as judged by colleagues and instructors).

The topic of this investigation must fall within the general area of science or a related discipline. We are open to discussion and persuasion if you have an interesting topic.

You will notice that at least four conferences will be scheduled before you begin work. In preparation for these conferences, groups will meet, discuss, and develop ideas and research projects. At these formal meetings *all* group members *will* be present.

Schedule for Group Investigation (see below for further discussion)

Prior to Sept. 3	Group formation and initial discussion
Sept. 3–14	First Conference • Topic identification • Several tentative generalizations and research hypotheses
Sept. 24–Oct. 5	Second Conference • Selection and refinement of generalizations and research hypotheses
Oct. 15–26	Third Conference • Experimental design, null and alternate hypotheses, and statistical methods
Nov. 5–16	Fourth Conference • Draft of proposal, preliminary studies
Nov. 16	Individual proposals *(typed)*
Nov. 26–30	Fifth Conference • Discussion of results/analysis and draft abstracts/reports
Dec. 4/6	Reports and classroom presentations

The instructors of this course are available to assist you *but*, you must expect to make an appointment to discuss the project. Conferences often take an hour or so. If you make an appointment—*keep it*!

Please don't badger or harass other instructors before discussing the reason with one of us to make sure it is worth both your time and that instructor's time. Be courteous, and expect to have to make an appointment.

The most important component of this exercise is discipline, an early start, and diligent cooperation through to its completion. Many projects will require preliminary studies, all will require some information sources or literature research and the development of some techniques. If you put off starting, you will be putting off finishing—past the end of the course—and that will have grade implications. Remember, you need to be finished in time to write the final report—so set your research deadline earlier than the day before the last class period.

Start early. Before the first conference, whether formally or informally, confer with other groups members and the instructors.

Throughout this exercise, from generating the research hypothesis and devising the experiment, to conducting the test, analyzing the data and writing the report, you should rely on all the ideas and principles discussed in the course.

Where Do Research Hypotheses Come From?

Research projects are essentially divided into two phases:

1. Conjecture: The inductive/intuitive generation of a research hypothesis.
2. Refutation: The deductive testing of the research hypothesis.

When we discuss the process of science, and when we read or write papers dealing with investigations, the process of refutation frequently receives greater attention than does the conjecture. This is unfortunate because it fails to do justice to the amount of time spent on the first stage of the process. The generation of a reasonable, meaningful, clearly stated, and testable research hypothesis may take considerable time, literature research, discussion, and modification/revision. During this process, you may severely modify or reject your initial research hypothesis. The process whereby you generate the research hypothesis that you ultimately will test is itself a circular one in which you generate one or more tentative hypotheses, and then test them through discussion or consultation with literature and experts.

Frequently, your first tentative research hypothesis is quickly answered. The literature research usually leads you to modify your thinking; it may lead you to the next question, and a much improved research hypothesis (Figure 11.8). You may travel the cycle of modification of research hypotheses through thought, discussion, and literature review several times before generating the final research hypothesis that you will test.

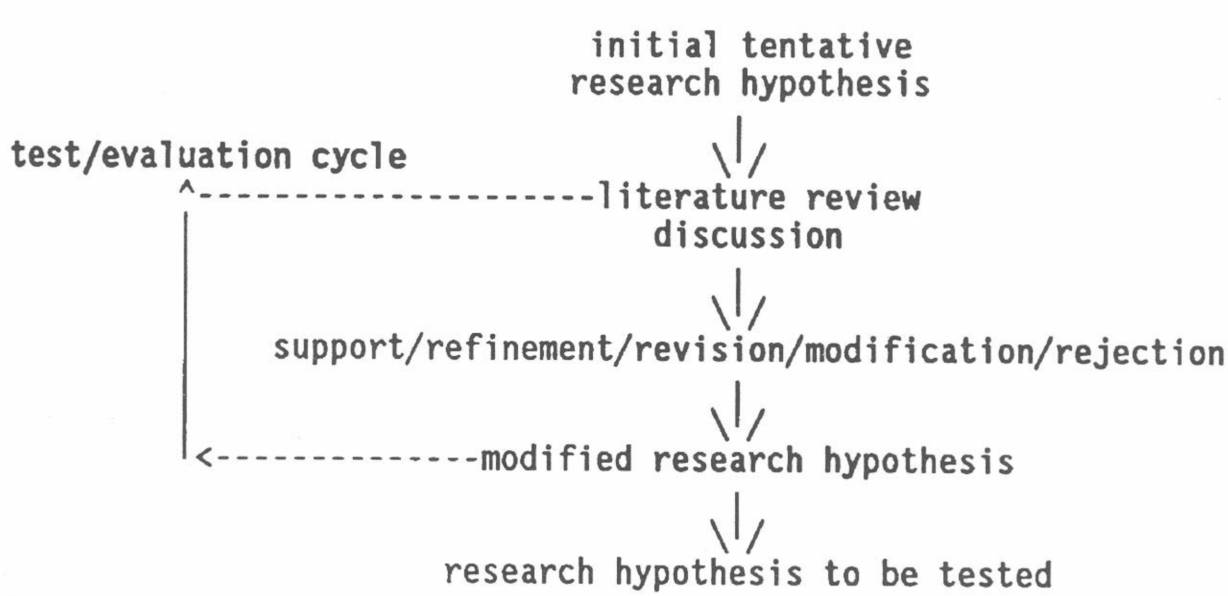

Figure 11.8. The development of a research hypothesis. Modified from O'Keefe and Journet (1985).

You are advised to start thinking about this investigation in plenty of time. If you postpone consideration of this project until the day, or even the week of the proposal deadline, you will not have time to undertake a worthwhile investigation.

Research Project Schedule

Group Formation

This exercise contributes significantly to your course grade. Effective completion of this assignment will require the commitment and dedication of *all* group members. If you are in a group with a student (or students) who are not interested in getting a good grade in the course (or even in passing), your grade will probably suffer. Furthermore, you will have to do much more than your fair and just share of the work. You are advised, therefore, to consider, both before joining a group and in the early weeks of group activity, how committed all group members are to satisfactory completion of the project. One way of judging this commitment is in the effectiveness with which students have performed regular assignments so far in the course. Another way to judge is by how willing group members are to arrange a meeting during the first week to discuss topic ideas.

As with all group activities in the “real” world, the primary responsibility for ensuring the successful completion of the project will be the group members themselves. You, therefore, have two responsibilities to yourself: (1) make sure you don't join a group that contains parasites, and (2) make sure you are not a parasite in the group.

We do not expect you to win a Nobel Laureate from this research. The emphasis in this exercise is not on complicated methods, advanced analytical equipment, or research on the “cutting edge” of science, rather it is on the development and conduct of a well-reasoned, well-organized, and well-conducted investigation. Elegance and simplicity will be rewarded, providing the hypothesis satisfies the criteria for quality determined through class discussion.

If you have not joined a group, you will be assigned to a group.

First Conference

In preparation for the first conference, group members should meet and discuss what topics or areas interest them. Within each group, members should try to think of some observations or information that has led them to form generalizations. The essence of the first conference will be a discussion of topics and potential generalizations that group members have identified. The outcome of the conference, we hope, is some narrowing down of possible topics, generalizations, and tentative research hypotheses to three or fewer. The group assignment will then be to consult some literature on these initial ideas to refine them for the second conference. Record (e.g., on 4×6 cards) all information and references you consult.

Second Conference

This will involve a discussion of the ideas and information sources that have been consulted and what they say about the tentative research hypotheses that are still under consideration (bring the list to the conference). Modified and improved research hypothesis/es should be the result. What competing hypotheses might explain the pattern you are investigating? After this conference, the group should have decided upon a research hypothesis that they wish to investigate.

The assignment will be to consider experimental design in detail, with particular reference to the experimental alternate and null hypotheses and the statistical techniques to be employed.

Third Conference

At this conference the experimental design will be discussed in relation to statistical analysis, experimental hypotheses, and any preliminary studies necessary. During this process some modification in the research hypothesis may be necessary to accommodate limitations in experimental design. Your experiment should be designed to address and eliminate possible competing hypotheses (i.e., getting the right result for the wrong reasons).

The assignment will be for *each group member separately* to type a draft of the research proposal. *Each group member should have a completely independent proposal—there must be no hint of copying or paraphrasing from one another's work.* Written in the future tense, the proposal comprises the regular report headings INTRODUCTION and METHOD, including source citations and the reference list. If this is well-written, it will require little or no re-write for the final report. Consider your audience: colleagues in this class.

Fourth Conference

By this time typed drafts of the research proposal should be available for discussion during the meeting and review of methods and any problems expected.

Proposal Presentations

Before actually conducting any investigation, it is common practice to write a detailed proposal of the project. If you were seeking funding for the study, this would be essential, and it would include a budget. But we don't ask for a budget. Final proposals will be submitted.

Conduct of Research

During this period you will be undertaking the research itself. It is imperative that **all** members of the group contribute equally to all aspects of the research study. Upon completion of the study, group members will evaluate the contributions that one another have made (a bonus is assigned to the evaluation provided you by your colleagues).

Fifth Conference

We all hope your research has been completed by now. This conference will involve a discussion of your results and statistical analysis *and* what the results mean for your research hypothesis and why you thought it. A first draft of the final report/abstract would enhance this discussion.

Final Report/Abstract Submission and Presentation
Research Presentations

You will be typing and submitting a collective report and abstract (previously I have required individual reports/abstracts) *and* making a collective presentation of your research; again, beware of plagiarism, include ample discussion, write for *your* colleagues in the class. The same time allowance as above will apply. Again, each member of the group will receive an individual grade on the report/abstract and a collective grade on the presentation. This presentation should:

1. Review the Research Hypothesis and reasons for it.
2. Identify the prediction.
3. *Briefly* outline the method identifying HR, HAs and HO.
4. Report results, including statistical analysis.
5. Emphasize discussion . . . what does it all mean?

Each group should also produce some appropriate visual aids to assist the audience to understand the results.

The audience will be evaluating the presentations using the format below. These evaluations will pass through the instructor to the presenters.

Coda

Assessment is based primarily on student written assignments (preparations and study guide questions), reports/abstracts, and an open-book final examination that tests the ability of students to apply their scientific reasoning.

This is an easy course for neither students nor instructors. Especially for students it requires a new approach to science, a new way to thinking about science, a way that high schools unfortunately fail to offer. But, the experience students gain provides them with insights into the scope and limitations of science that it would be impossible to gain elsewhere. Without this experience, many would still complete a baccalaureate in science without knowing how science works. Considering the rarity of such experiences in the nation, it is little wonder that the high school experience is so numbing to students; most of their teachers have simply never conducted a scientific study themselves and cannot, therefore, hope to convey to their students an understanding of science, much less the excitement that investigation offers.

Not all subsequent courses in the major require that students practice science or apply scientific reasoning. Those faculty (including this author) teaching later courses that do require these skills, find this course prepares students for both laboratory and theoretical assignments that demand an understanding of the process of science. Because transfer students (from other universities or junior colleges) are weak in their understanding of the scope and limitations of science, we offer a single credit course that is just the laboratory component. Transfer students are strongly advised to take this course.

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