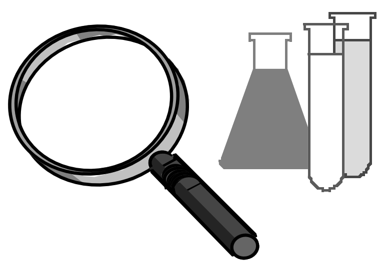
ENCOURAGING STUDENT BIOLOGICAL RESEARCH

through

TEACHER-SCIENTIST PARTNERSHIPS



Scientists are masters of precision.

Teachers are masters at clarity.

And students are masters at spontaneity.

—Daniel Barstow, 1996.

ABOUT SAFETY

The safety procedures included with each investigation were written to assist teachers in conducting the *Student Research* investigations with their students in precollege classrooms. While every effort has been made to anticipate questions and situations that could arise, the safe implementation of these investigations must depend on the good judgment of teachers and is the responsibility of the local school district/institution. We suggest that teachers consult state or local safety manuals or textbooks for additional information. In some schools, it may be necessary to obtain special permission to do some of these investigations with students, since they involve certain organisms. We suggest that teachers check with their principal, science supervisor, scientific research review board, and/or school board to see what procedures may be required.

NABT recognizes the pervasive social phenomenon of litigation with respect to even the most unfounded claims. For that reason, NABT disclaims any legal liability for claims arising from the use of these investigations. This information has been provided to teachers and schools as a service to the profession and we provide this material only on the basis that NABT has no liability with respect to its use. Responsibility for use of any of this information is assumed by the local district/institution.

NABT believes that under the guidance of a properly trained and responsible teacher all of the *Student Research* investigations can be conducted safely in high school classrooms.

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Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation or the National Association of Biology Teachers.

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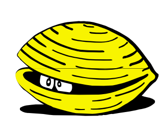

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Each Core Experiment and its Variations is dynamic and is intended to be a springboard for you, the user of this material, to launch your students into the exciting world of scientific research.

Introducing the Student Research Investigations

• How the Investigations Are Set Up and the Rationale Behind Their Design

Each investigation has a Core Experiment with up to ten variations. To show the relationship between the Core Experiment and the Variations, check the first page of each lab. Here you will find an At-A-Glance Map of how each variation relates to the Core Experiment. The writing format for the investigations and a brief description of each section are included where appropriate in Appendix A. Each activity is divided into two sections— Directions for Teachers and Directions for Students. The Directions for Teachers section contains a wealth of information for the teacher when conducting student research such as content background, teaching tips, time considerations when preparing and conducting the investigation, instructional strategies, suggested readings, common student misconceptions, sample data, interpretation of the data, and sample questions with answers. The Directions for Students section is a guide for students to conduct their own research under the guidance of their teacher.

• Background on the Writing Partnerships Between the High School Teachers and Scientists

Recruitment of teachers was done by project staff through visits to school districts and mailings to NABT members and science supervisors of public and private school districts in North Carolina, Northern Virginia, Washington, DC, and Maryland. Sites at which teachers were recruited were specifically chosen to include students of diverse cultural, ethnic, and socioeconomic backgrounds. In many cases, teachers interested in participating in the project applied with scientists with whom they had worked previously. This arrangement was—and is—the most successful. Already established teams have the rapport necessary for a smooth working relationship. In other cases, teachers were paired by site facilitators and NABT staff with scientists with whom they had not worked previously. All teacher and scientist partners were required to work together during the application process to develop an idea for a laboratory experiment. This provided the opportunity to establish rapport before the summer work began.

Twelve teams were selected from the Central North Carolina area and the Greater Metropolitan Washington, DC area. Originally, each team consisted of two teachers and one scientist who worked together to develop an idea for a laboratory experiment. At the conclusion of the lab development, two teams consisted of one teacher and one scientist, and a third team had two teachers. In the latter case, one teacher had done scientific research previously. Attrition was due to change in work responsibilities and job relocation.

During three-day workshops held at the North Carolina and the District of Columbia sites, the teams were updated by experts in the field on topics such as computer use, the process of scientific research, guidelines for supervising student research, modifying investigations for students who are exceptional, scientific writing, literary research and review, laboratory safety, and pedagogical strategies. At the conclusion of these workshops, the teams formed working schedules for a period of 30 days over the summer to develop their respective lab topics for pilot testing in the teachers' classrooms the following school year. Site visits were made by the NABT staff to each lab site during the summer and to each school during the following school year to assess the progress of the development.

In Year II, a debriefing of the 12 teams was held on the campus of North Carolina State University. Teams presented their labs and findings to each other and shared successes and difficulties they encountered during development and pilot testing of their projects. In addition, teams received workshop training so that they could present their findings to teachers in their school districts and, where possible, nationally. The labs were modified to include the input of other team members. At this time, it was decided that fewer than half were ready for national field testing and another year of development was necessary for the remaining labs. In all, the labs were field-tested over a three-year period. In the last year, all labs were field-tested specifically with students who are exceptional.

The development of this project reflects the ongoing process of science. Each Core Experiment and its Variations is dynamic and is intended to be a springboard for you, the user of this material, to launch your students into the exciting world of scientific research. Those teachers and scientists involved have shown a commitment to science and science teaching that is exceptional through their extraordinary efforts and dedication throughout this process. Every Core Experiment and its Variations is the result of years of development and effort to provide the best science and pedagogy for biological scientific research. The project participants understand that this is a process and that the findings in this document will change over time with use. Each teacher who uses these investigations has the benefit of the participants' time and knowledge of this project.

• *Some Practical Points About Experimental Design and Open-Ended Investigations*

There are many sources of information for experimental design. An excellent resource that should be part of every biology teacher's library is *Students and Research* by Julia H. Cothron, Ronald N. Giese, and Richard J. Rezba. First published in 1989 and commonly known as the "Red Book," *Students and Research* contains a wealth of information on basic and advanced principles of experimental design and analysis and strategies for managing effective student research. This publication is available from Kendall/Hunt Publishing Company. ISBN: 0-8403-7766-5.

• *Safety Issues Involved in Student Research*

There are many guidelines for laboratory safety. Establishing a safe environment is paramount to the responsibilities of the teacher and his/her institution and to the successful, safe experience of the student. The most effective way to establish a safe environment is for the teacher to model safe conduct in the laboratory and to set clear expectations of students and their behavior in the laboratory. The goal of laboratory safety is to prevent an accident. The Tips for a Safe Laboratory Environment, located in the sidebar, while not inclusive, are some common measures that you can take to establish a safe laboratory environment.

TIPS FOR A SAFE LABORATORY ENVIRONMENT

- Know how to read and interpret Material Safety Data Sheets (MSDS). Have one on file for each chemical in the laboratory.
- Know how to read and interpret the information and symbols on chemical labels.
- Know how to store, handle, dispose of, and inventory each chemical that is being used in the laboratory.
- Take a laboratory safety class.
- Plan well ahead.
- Maintain a clean and organized laboratory.
- Anticipate student accidents.
- Never leave students alone in the laboratory.
- Identify and review the location and correct use of safety devices within the laboratory and procedures on a regular basis.
- Have the proper safety equipment. If you do not have it, do not do the lab.
- Always wash hands before and after the lab.
- Clean up spills immediately.
- Provide time for proper lab cleanup.
- Have a phone in the laboratory.
- Post phone numbers for poison control, fire, police, and hospital beside the laboratory phone.
- Know the location of the master shutoff for gas, electricity, and water.
- Clearly label all paper, glass, and chemical waste containers.
- Use alcohol thermometers in place of mercury ones.
- Practice fire and evacuation drills on a regular basis.
- Give clear instructions that relate risks and demonstrate techniques for students.
- Expect exemplary behavior. Do not tolerate unsafe behavior.
- Expect students to have and wear the necessary safety equipment.
- Form and enforce written contractual agreements between the student and the teacher that clearly define safe laboratory behavior and expectations.
- Instruct and review with students the safe handling of equipment, materials, and organisms.
- Do not permit students to eat, drink, chew gum, apply cosmetics, or wear contacts in the laboratory.

TEACHER'S NOTES

• *General Guidelines for Supervising Student Research*

General Considerations for Teachers Overseeing Student Research

- Insure that students select a project that is "doable" in the given amount of time.
- Allow sufficient time for students to write up their results and prepare a display for science competitions.
- Set deadlines for students, and hold them accountable.
- Help students initially choose a project that has a good chance of giving a definite "yes" or "no" answer. If, for example, techniques involved are too difficult for the particular students to perform, the data may be inconclusive and students will become frustrated.
- Make students aware of science competitions—local, regional, state, and national—early in the year so that they can plan their research around it.
- Schedule frequent, periodic, individual meetings with students.

Time Line Sample

One important consideration when doing student research is developing a time line that is achievable with expected goals. A possible schedule for student research follows:

Week 1: Introduce experimental design and how to select a topic.

Week 2: Topic due. Begin to make entries of topic considerations into a science journal/log.

Week 3: Topic approved by teacher; begin literary search; record all information in journal.

Week 4: Hypothesis due. Literary search continues.

Week 5: Hypothesis returned; select a mentor; begin research plan.

Week 7: Research plan due; mentor's name and contact information due; all protocol forms due; Animal Review Board (ARB) and Internal Review Board (IRB) paperwork due, if applicable.

Week 8: Research plan returned and research begins if no paperwork is required.

Week 9: Paperwork approval received, if appropriate.

Week 10: Research plan with paperwork submitted to regional Science Review Committee (SRC).

Week 11: SRC returns papers. Research begins.

Week 12: Data check.

Week 16: Data check.

Week 20: Rough draft of scientific paper due.

Week 21: Abstract due.

Week 24: Final copy of scientific paper due.

Week 25: Preparation of display of scientific findings.

Week 27: Presentation of findings to the class and/or entrance into scientific competitions such as science fairs and junior academy.

Topic Selection (Source: Kathy Gotshall, Melbourne H.S., Melbourne, FL)
For most students, selecting the topic and developing a sound question are the "hardest" parts of the science research. A few weeks should be spent in general reading, browsing, and brainstorming. The topic may change several times. Encourage the students not to become discouraged. Topic selection is mainly a matter of pinpointing what interests them in science. When selecting a topic, students should take the following into consideration:

- Be certain that the topic will be interesting and doable within the allotted time period.
- Design an experiment that will contribute to science by exploring an aspect of a problem not considered before, refuting a past experiment, carrying a past experiment further, studying some natural event by finding a cause-effect relationship, or adding to the general store of scientific knowledge.
- Plan to use inexpensive and available equipment and resources.
- Choose a topic that is challenging, but that is not so difficult that one feels defeated before he/she begins. Questions like the following will help define areas of interest.
    * What is the most interesting science course you have ever taken? Why?
    * What is the last science museum you visited? What exhibit do you remember best?
    * What are your hobbies or is there a hobby that you would be interested in starting? In what ways could you incorporate your hobby into the project?
    * Have you decided on a career? If so, what is it?
    * Do you have a job? What is it?
    * Look at the list of categories of biology. Which three in order interest you the most? The least?
    * Have you done a science project before? Is there room for a further experiment?

Literary Search (Source: Author Unknown)
The literary search provides information on the topic selected and helps the researcher to become knowledgeable about the topic, what research has already been done, and what questions have been formulated from previous research. When doing research, students should be aware of the sources of information—primary or original sources of information, secondary sources or distillations of the original work, and tertiary sources that usually index or refer to the original work and distill the work even further. Primary sources include journals, experimental results, theses, summaries, monographs, interviews, questionnaires, memoirs, manuscripts, meeting reports, patents, and diaries. Secondary sources include abstracts, reviews, and journal indexes. Examples of tertiary sources include abstract indexes, author indexes, subject indexes, and formula indexes.

"How does one derive the most from a literary search?" Begin with a primary, secondary, or tertiary source to develop the topic. Remember that "searching" is an art. No precise methods can be spelled out because the material often is not listed verbatim in the way you want it. A certain amount of imagination and creativity is required to think of useful key words or nomenclature. A broad view of the project's subject area and of the project's purpose while searching the literature often will produce serendipity or eliminate the need for additional surveys.

TEACHER'S NOTES

You may wish to introduce students to a literature search by providing the following:

The Literature Search

You now have a tentative topic. You have read a book, done an experiment, or heard a discussion about your chosen topic, and now you want to get started.

Here's How To Start

1. Write down the aspects, methods, and key words that prompted you to select your topic.
2. Obtain a dictionary, handbook, and an encyclopedia to define terms and expand your original key word list. This will give you a clue or orientation as to further avenues for exploration.
3. Find a recent textbook appropriate to the topic. Use the glossary to find the pages where your key words are contained. These pages will give you access to more key words, names of authors, and lists of articles of interest. You also may conduct this search on-line, but be very selective with the sources that you find.
4. An annual review also should be consulted if your topic focus is still vague or too nebulous.
5. Consult the appropriate abstracts. These may be found on-line. Abstracts list in their indexes subject areas, authors, and journals which may be of use. Often the actual abstract provides a synopsis of the article's content (method of preparation, constants, results, and implications).
6. Your last step of this process should be accessing and reading the original literature.

As you review the information you have collected, select those articles of further interest. In all cases, the original literature will have a bibliography leading you to more information about articles or authors.

Recording Information

You will need your journal to record information from your literature search. Making a duplicate copy of your work on some other medium makes sense. You will need a separate page for each reference to keep it available at all times when you are working on your sources. Your recording system should contain a separate entry for:

- Author
- Title
- Facts of publication
- Page numbers
- Descriptive statement(s) with regard to content of the reference—also make a judgment of its usefulness
- Questions to pursue

After you have sorted through your sources and have identified those articles, books, or authors that more than likely will be included as your references, you need to:

1. Restate the article's content in your own words.
2. Use direct quotations from the reference to support, compare, or contrast your position.
3. Make critical/evaluation comments about the article.
4. Cross-reference to other articles that support or dispute this article's position.

Use this information as a guideline in your literature search and your efforts will be rewarded accurately and quickly. Good searching!

Weekly Progress Meetings

An individual 10-minute conference may be held with each student to discuss progress to date every other week initially and monthly thereafter. A record of the meeting and plans to be completed before the next meeting can be made and a copy given to the student. This record is another means of holding students accountable. If possible, set aside a particular area of the classroom or lab specifically for research by individual students. Have students keep a journal of all work done on the research project and bring it to each meeting along with their time line for meeting the components of the research. Check the student's progress regularly. A sample form for the meeting is shown here:

Research Progress Report

Date: ________________________ Time: _____________
Name of Student: _________________________________
Name of Teacher: _________________________________

1. I have completed and am on schedule with the following tasks related to my research project at this time:

____
____
____
____

2. I have been having the following challenges accomplishing these tasks:

____
____
____
____

3. I plan to address these challenges in the following ways:

____
____
____
____

4. By the next meeting, I plan to address the following tasks:

____
____
____
____

_______________________ _______________________
Student Signature Teacher Signature

• Where to Find Mentors and the Role They Play in Student Research

One of the main reasons for the *Student Research* project was to develop a way for teachers to handle multiple student experiments more easily. Student research usually occurs within the classroom in conjunction with the annual school science fair. Some schools do have programs that are dedicated to student research classes, but these are rare. Research may be conducted at school or off the school campus in a research institution where students work as interns. Depending upon the researcher and the time that is available, students may conduct literary research, perform original research under the guidance of the scientist, and presentations of findings in journals and/or at scientific conferences, and/or provide lab tech support. This form of research is done out of the arena of the classroom in many cases and on the student's own time.

The other main way that research is conducted in the high school classroom is through science fairs. Students may do the research at a scientific laboratory under the guidance of a scientist or literally on the kitchen table at home. In these instances, it is not uncommon for one classroom teacher to have 120 separate experiments of various levels and content taking place. It is impossible for one person to mentor each separate activity appropriately. The role of a mentor is crucial to the success of the student's research.

Mentors may be found in all arenas from research institutions to special interest groups, such as gardening clubs. Many professional societies, two-year and four-year academic institutions, industries, hospitals, government agencies, and research institutions have education departments for facilitating student research. Locating mentors for each project can be a time-consuming process. The sharing of topics within a class can provide access to parents or individuals in their workplace who can mentor student labs. Each Core Experiment lists possible mentors specific for the lab content.

The successful mentor is one who enjoys working with youth, has a passion for science and the patience to teach and convey this passion to youth, and acknowledges his/her responsibility to give back to society for the benefit of future generations.

• Where to Find Student Research Opportunities

A list of sites offering opportunities for high school students in research follows. The list is by no means exhaustive, but provides an idea of the vast opportunities for students to participate in original research.

NIH Summer Internship Program in Biomedical Research: *http://www.nhlbi.nih.gov/nhlbi/train/redbook/hsnihbio.htm*. This program enables students who have a strong interest in pursuing studies related to biomedical or behavioral research, including the disciplines of biology, chemistry, physical science, psychology, computer science, biostatistics, mathematics, and biomedical engineering, to receive a research experience at the National Heart, Lung, and Blood Institute (NHLBI).

High School Extramural Programs: Research Supplement for Underrepresented Minority High School Students: *http://www.nhlbi.nih.gov/nhlbi/train/redbook/hsminsup.htm*. This program is designed to provide support for research experiences for underrepresented minorities, which includes African Americans, Hispanics, Native Americans, Alaskan Natives, and Pacific Islanders.

Research Supplements to Promote the Recruitment of Individuals with Disabilities Into Biomedical Research Careers: *http://www.nhlbi.nih.gov/nhlbi/train/redbook/hssupdis.htm*. This program provides research experiences for qualified high school students with disabilities who wish to participate in an ongoing research project during the summer months or during the school year.

NIH Summer Internship Program in Biomedical Research: *http://www.nhlbi.nih.gov/nhlbi/train/redbook/hsnihsum.htm*. The NIH Summer Internship Program in Biomedical Research is intended to give students in high school an opportunity to participate in state-of-the-art research in the intramural laboratories at the National Institutes of Health.

NINDS Summer Program in the Neurosciences: *http://www.nhlbi.nih.gov/nhlbi/train/redbook/hsnihsum.htm*. This program provides hands-on neuroscience research training for academically talented high-school students contemplating a career in biomedical research or academic medicine.

Student Career Experience Program: *http://www.nhlbi.nih.gov/nhlbi/train/redbook/hsnihsum.htm*. The Cooperative

Education (COOP) is a planned and progressive, career-related student employment program.

Summer Research Fellowship Program in the Neurosciences: *http://www.nhlbi.nih.gov/nhlbi/train/redbook/hsnihsum.htm*. The NINDS Summer Research Fellowship Program in the Neurosciences is designed to give academically talented students a unique opportunity to acquire valuable hands-on research training and experience in the neurosciences.

High School Science Student Education Program: *http://www.mcw.edu/research/student/roads.htm*. Aimed at advanced chemistry, biology, and physics classes, this program provides experiences in the world of science at the Medical College of Wisconsin.

Mini Medical School for High School Students: *http://www.mcw.edu/research/student/roads.htm*. This eight-week course, consisting of four lectures and four corresponding laboratories, is designed for the advanced high school science student who wants to delve deeper into current biomedical topics and who may be considering a career in biomedicine and research at the Medical College of Wisconsin.

Research Opportunity for Academic Development in Science (ROADS): *http://www.mcw.edu/research/student/roads.htm*. The ROADS program allows minority high school students interested in science to serve as research fellows for eight weeks during the summer.

High School Leadership Training Programs: *http://www.ssc.org/summers/sprog.html*. The Sierra Student Coalition presents three national high school environmental leadership programs designed to train the leaders of the present and the future located in Colorado, Virginia, and Vermont.

"PPD: Biotechnology Works!": *http://www.workpage.com/g/07/283g.htm*. Recognizes the National Science Foundation's priority to facilitate the participation of persons with disabilities in mathematics and science.

Summer Apprentice Researchers at QUEST: *http://www.quest.ucsb.edu/education/ARQ/ARQ.html*. The Apprentice Researcher at QUEST (ARQ) program for high school students and teachers is supported by supplemental funds from Education and Human Resources at NSF. Participants conduct research through scientific inquiry, use sophisticated equipment to observe and analyze data, and recognize how mathematics and scientific theory apply to the labs of successful career scientists.

SEACAMPS San Diego and Hawaii: *http://www.seacamp.com/summer/summer.html*. This co-educational residential program for students who will be entering the 7th through the 12th grade in the upcoming school-year.

• *Modifying These Investigations for Students Who Are Exceptional*

In all efforts to educate youth, it is essential to accommodate all learning needs where possible. The AAAS *Barrier-Free in Brief* series is an excellent source of information on science/mathematics learning and disability. The four-booklet series is unique, succinct, and reliable. Some of these booklets have addresses of agencies that can provide information about obtaining assistive technology, such as Assistive Listening Devices (ALDs), light probes, and talking thermometers, calculators, and clocks. Any one or all of the booklets are available FREE from AAAS, Project on Science, Technology, and Disability, 1333 H Street, NW, Washington, DC 20008; 202.326.6630 (V/TDD); 202.371.9849 (FAX); bgoodric@aaas.org (E-mail). Lab-specific suggestions for accommodating the needs of exceptional students are found in the section entitled Suggested Modifications for Students Who Are Exceptional for each Core Experiment, and where appropriate in each Variation of the Core Experiment. Students already may be able to provide their own modifications. Be sensitive to the student and his/her needs and discuss these issues with him/her before suggesting any modifications. The modifications suggested here do not begin to address all the needs students with single and multiple special needs may have when conducting these investigations, but should provide suggestions to accommodate some.

• *How the Student Research Investigations Address Assessment and Standards*

Today, accountability is a function imperative in education. Assessment of what is learned and standards for that learning provide accountability for the processes and content of each learning environment. The contents, skills, and objectives of *Student Research* have been correlated with the software package *Curriculum Orchestrator* produced by *MediaSeek*. This software package has a science knowledge base that links the *Student Research* publication to national and state standards as well as other publications and various media. It is available from *MediaSeek* Technologies, Inc., 2211 Rimland Drive, Suite 224, Bellingham, WA 98226-5662, 800.372.3277. The *Student Research* labs seek to involve students actively and intelligently in the process of scientific investigation. The active involvement of students in scientific investigations is the essence of the science education standards. The investigations have been aligned with the *National Science Education Standards* (*NSES*) developed by the National Research Council and the *New Standards™ Student Performance Standards* developed by the National Center on Education and the Economy. Each set of standards has been placed in a matrix. A check mark indicates which activity is aligned with the appropriate standard for each document.