1

Beginning a STEM Research Project

Introduction

Science, technology, engineering, and mathematics (STEM) research refers to experiments conducted to address problems in those fields that can be tested using the scientific method. The *scientific method* is an inquiry process used to systematically study, investigate, and to provide explanations for observed phenomenon in the natural world. This method is used by STEM professionals to answer questions they have about important world problems and usually includes carefully orchestrating a situation that allows them to observe, measure, and test their ideas (Valiela 2001). This "situation" is known as an *experiment*. Most experiments include a hypothesis; a variable that can be manipulated by the researcher; and variables that can be observed, measured, calculated, and compared. When possible, these experiments are completed in a controlled environment.

Learning Objectives

By the end of this chapter, you should be able to

1. identify resources that can be used to generate research ideas,
2. list possible research topics,
3. put preliminary research ideas into testable questions, and
4. apply safety and ethical issues to your own project ideas.

Note to the teacher: These objectives are restated in the form of questions at the end of each chapter (e.g., see p. 11). The questions can be used to check for understanding after the class has completed the chapter.

Key Terms

Data: The measurements and observations that are collected as part of a research project, often a combination of measurements and descriptions.

Dependent variable: A dependent variable is what you measure in the experiment and what is affected during the experiment. The dependent variable responds to the independent variable. It is called dependent because it "depends" on the independent variable. In a scientific experiment, you cannot have a dependent variable without an independent variable. (Source: *www.ncsu.edu/labwrite/po/dependentvar.htm*)

Entity: The subject, specimen, or item that is studied as part of a STEM research project.

Experiment: The test conducted as a part of the scientific method that includes a hypothesis; a variable that can be manipulated by the researcher (independent variable); and variables that can be observed, measured, calculated, and compared (dependent variables).

Independent variable: The variable you have control over, what you can choose and manipulate. It is usually what you think will affect the dependent variable. In some cases, you may not be able to manipulate the independent variable. It may be something that is already there and is fixed or something you would like to evaluate with respect to how it affects something else. Example: You are interested in how stress affects heart rate in humans. Your independent variable would be the stress and the dependent variable would be the heart rate. You can directly manipulate stress levels in your human subjects and measure how those stress levels change heart rate. (Source: *www.ncsu.edu/labwrite/po/independentvar.htm*)

Scientific method: The scientific method is an inquiry process used to systematically study, investigate, and provide explanations for observed phenomenon in the natural world.

STEM research: Experiments that test hypotheses in science, technology, engineering, and/or mathematical fields.

The word *data* refers to the measurements and observations that are collected as part of a research project. The kinds of measurement data commonly collected in STEM fields are *acidity/alkalinity, area, circumference, density, electrical current/potential/resistance, force, growth (time, weight, volume, length/width), heat, humidity, light intensity, mass, pressure, sound intensity, temperature, time, velocity, volume, and weight*.

Data can also be collected by describing observations and using words and photographs. In that case, one asks, How does [something] look, smell, sound, feel, and taste (when appropriate)? These types of observations supplement the measurements taken throughout the experiment. A combination of measurements and descriptions are listed to determine whether the proposed idea of the experiment is supported by the data.

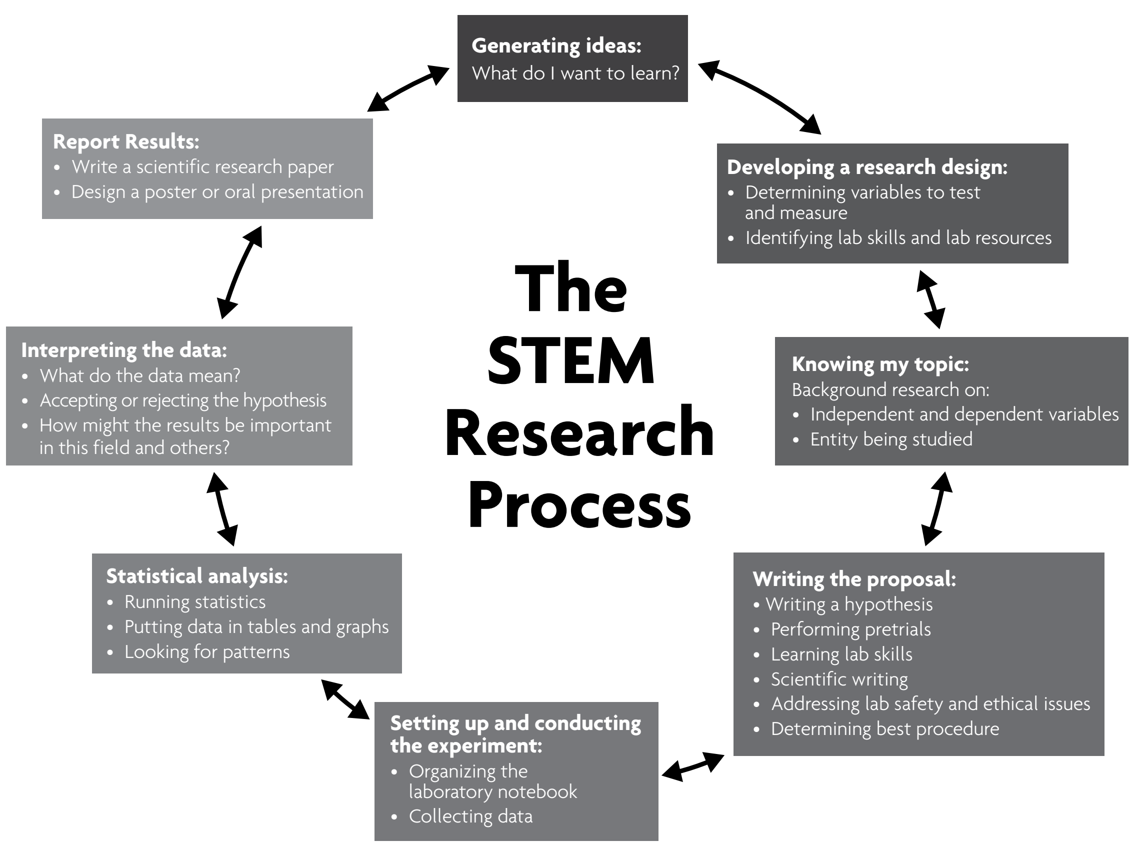
You have probably taken many science courses where the first chapter of your textbook presents the scientific method. Have you ever noticed that the "steps" in the scientific methods are rarely ever worded in the exact same way? Why would that be? Isn't science supposed to be about accuracy and step-by-step procedures? First you do this, then you do that, so that you can collect this and write about that. So here's my challenge to you: Do not think about the scientific method as steps or procedures that a scientist must complete before he or she gets answers to the questions that were asked.

Instead, think of the scientific method as doing your absolute best to answer a question with the knowledge, skills, resources, and technology you have available. Could someone else, with different skills and technology, answer the same question in a different way? Absolutely. But this should not keep you from answering it your way. Could it mean that your design will be obsolete in a couple of years when new technology is available? You bet! But this is no excuse for not doing what you can with what you have. This also highlights the importance of STEM professionals sharing what they have learned, both successes and failures, through journal articles and conference presentations, so that everyone doing research in that area can benefit from what each has learned.

Real research can be messy. Therefore, when I talk about the scientific method, or the general research process, I use the word *stages* rather than *steps*. The word *step* suggests each step is an equal distance from each other, and that once you have reached the top step, you should be embarrassed to

Figure 1.1

Stages of STEM Research



have to go back to the first step. But in real science, this is exactly what happens. Learning, by its very nature, can lead us in many directions, and often, it is in the moments when we have to go back and rethink or retest something we previously studied that the best discoveries can be made.

While moving through the stages of the scientific research process, you will soon learn that in scientific inquiry, the more you know, the more you know you don't know. That is, as you gain more insight to a problem, you usually come out with more questions than you do answers. It is even possible that you do not answer the question you started out to answer but another question entirely. And for most STEM professionals, the emergence of new questions is celebrated, not frowned on. However, take heart. It is likely that your teacher, who is overseeing your research project, wants to help you develop a research study that is not too messy. So, as you get feedback from your teacher about possible modifications to your research design (see Chapter 2), it probably is in your best interest to consider them.

Generating Research Ideas

More than likely, you are curious about various things, including things that you have seen recently. Maybe it was something you saw in a movie, in the news, or around your house or school. You wondered to yourself, *I wonder if that is really possible* or *I wonder if the same thing would have happened if….* Questions like these are the seeds of great research ideas. Thinking about how the world functions, and how you might improve it, is at the heart of STEM research. The first stage of generating a research idea is to determine several entities you might be interested in studying. For the purposes of this handbook, the term *entity* refers to the subject, specimen, or item that you will study for your STEM research project.

Getting started on a research project often brings with it two different dilemmas: Either students have no idea what they want to study or they have a very specific idea of what it is that interests them. I'd like to warn you to stay away from each extreme. It is best to have a general idea of what you want to study—that way you can focus your research—but you will not be so narrow in your thinking that you miss a great research opportunity.

This book doesn't include a list of specific research ideas from which to choose. There are plenty of other resources that contain research topics. However, here are some general tips on how to generate a research topic:

- Choose a topic that is interesting to you. Maybe there is a topic that you have always wanted to know more about. You will be working with this topic for a long time, so choose it carefully.

- Search for ideas on the internet. Look not only for research projects that have already been conducted but also for general information about the entity you might study and the items you might manipulate within the experiment.
- Reflect on a topic you heard about on television that piqued your interest.
- Think about issues your family deals with. Maybe there are personal reasons why you might be interested in a specific topic.
- Flip through a science or math book, magazines such as *Science News*, or encyclopedias for inspiration.
- Borrow your teacher's science supply catalogs (such as those from companies like Carolina Biological Supply or Flinn Scientific) and look through the different live specimens, chemicals, and apparatus that you could purchase or borrow.
- Think about the lab skills that you have already learned. How might you use those skills in a research study? Are there other skills that could be easily learned that you'd like to try?
- Ask your teacher for a list, or maybe a tour, of available equipment in your school that you could check out to use at home or use within the school's lab.

Many times just knowing the tools, instruments, or tests that are available to study certain topics can spark an idea for a research project. Use the list in Table 1.1 (pp. 6–7) to consider entities within STEM fields that you might study. Though you may think you have limited access to some of the equipment listed here, do not underestimate your ability to improvise. You may be able to design an instrument to measure what you want. And there are technologies you already have that you might use, such as your graphing calculator or cell phone. A calculator-based laboratory (CBL) system or calculator-based ranger (CBR), along with probes, might be easy to obtain from various departments at your school. Smart phones with inexpensive applications (apps) may also help you measure something if you do not have access to more expensive equipment.

Once you have a general topic, start asking yourself questions. Let your natural curiosity lead you to possible ideas to study. However, stay away from "why" questions—for example, "Why do more algae seem to grow in slower moving stream water?" They tend to be too broad and worded in such a way that they are not testable. Instead, you can rephrase a question to break it into

Table 1.1

Sample STEM Topics With Associated Tools, Instruments, and Tests

What to Measure	Tool, Test, or Instrument
Absorbance	Spectrophotometer (Spec-20)
Acidity/alkalinity	pH paper, pH meter
Altitude	Altimeter
Angles of slope/tilt	Clinometers, protractor, sextant, transit, goniometer, Geometer's Sketchpad
Area	Meterstick (with appropriate formulas), planimeter
Bacteria	Gram stain, incubator, hemocytometer, spectrophotometer
Blood pressure	Sphygmomanometer
Calculus	Calculus modeling and equation solving systems (Mathematica), graphing calculator
Color/pigments	Chromatography
Conductivity	Amperometer, potentiometer
Density	Balance and meterstick, pycnometer, hydrometer
Earth movements	Seismometer
Electrical current	Ammeter, multimeter, galvanometer
Electrical potential	Voltmeter, multimeter, galvanometer
Electrical resistance	Ohmmeter, wheatstone bridge
Embryology	Chick incubator
Force	Spring scale, dynamometer
Global position	Global positioning system (GPS)
Heat	Calorimeter
Humidity	Hygrometer
Insects (trapping)	Berlese funnel, bait trap, aspirator, sand/mud sieve, nets
Length/width	Meterstick, tape measure, micrometer, Vernier caliper
Light	Spectrometer, photometer, light meter, photoelectric cell
Mapping	Transit
Mass	Spring balance, lever-arm balance, electric balance
Mathematics	Geometer's Sketchpad, GeoGebra, statistical software, Mathematica, graphing calculator, TinkerPlots, Fathom

Table 1.1 *(continued)*

Sample STEM Topics With Associated Tools, Instruments, and Tests

What to Measure	Tool, Test, or Instrument
Muscle activity	Electromyography, video analysis
Muscle tone	Myotonometer
Optical density	Photoelectric colorimeter
Photosynthesis (rate of)	pH meter, chromatography
Plant growth	Time-lapse camera, metric ruler, protractor
Pressure	Barometer, manometer, mechanical pressure gauge
Radioactivity	Geiger counter, imization detector
Range of motion	Goniometer
Respiration	Respirometer
Salinity	Salinometer
Small live specimens	Light microscope, stereomicroscope, magnifying glass
Soil	Soil coring tube, screen sieve, soil thermometer, chemical tests (phosphate, nitrogen, potassium, pH)
Soil porosity	Soil samples, beakers, water
Sound intensity	Audiometer, decibel meter, sound-level meter
Statistical comparison	Statistical software like Excel or SPSS, Fathom
Temperature	Thermometer, infrared thermometer, thermocouple, thermistor, pyrometer
Tensile strength	Spring scale, metric ruler
Time	Stopwatch, timer, watch
Transpiration	Graduated cylinder, closed container
Tree diameter	Diameter tree measuring tape
Tree height (or other large entity)	Tangent height gauge
Tree wood quality/growth rate	Increment borers
Turbidity	Secchi disk, turbidity tube, turbidity meter
Velocity	Speedometer, anemometer, stopwatch/meterstick, stream flow meter
Viscosity	Stopwatch, calibrated tube, ball, funnel
Volume	Graduated cylinder, pipette, burette, volumeter, manometer

(continued)

Table 1.1 *(continued)*

Sample STEM Topics With Associated Tools, Instruments, and Tests

What to Measure	Tool, Test, or Instrument
Water collecting debris	Manta trawl
Water flow	Water flow probe or ball, meterstick, stopwatch
Water quality	Dissolved oxygen (kit or titration), pH
Water retrieval @ depths	Water sampler
Water turbidity	Secchi disc
Weight	spring scale, electric scale, balance
Wind speed	Anemometer

smaller parts, which *are* scientifically testable—e.g., "Which stream velocities encourage more growth of algae?" That question is now a measureable and, therefore, testable question. *Note:* Testable questions often begin with *How, What, When, Who,* or *Which.* Write several questions that you might be interested in studying. The Southwest Center for Education and the Natural Environment has an inquiry tutorial that can help you write some preliminary research questions (*http://scene.asu.edu/habitat/inquiry.html*).

Focusing Preliminary Research Topics

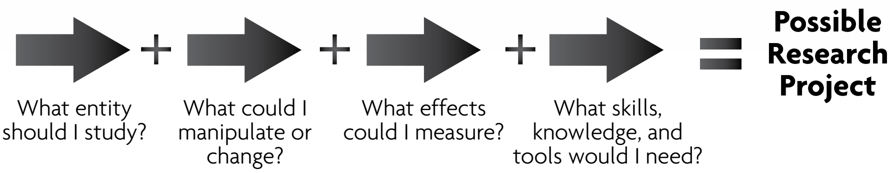
Once you have a preliminary research topic, you will need to focus it, using a new group of questions. Finding answers to each of these questions will help you get closer to what it is you will eventually study. Figure 1.2 shows the connection of the following questions: What entity should I study? What could I manipulate or change? What effects could I measure? What skills, knowledge, and tools would I need?

It is likely that your teacher will encourage you to narrow your "effects" (things to count and/or to describe) to only one or two items, most likely one or two you will measure and one or two you will describe. Use Table 1.2 as a guide as you complete "Student Handout #1: Focusing Preliminary Research Ideas," page 14. The goal of this stage is to brainstorm various combinations of the same research topic. Try and list as many answers to the questions in Figure 1.2 as possible. Don't worry yet about what will work, just generate ideas.

You may want to fill out Student Handout #1 several times, comparing a couple of ideas you are considering at this time. Your teacher may have you

Figure 1.2

Focusing a Research Topic



enter these preliminary ideas into your laboratory notebook (see Chapter 6). In addition to the various issues raised earlier in this chapter, you also need to pick a topic that is both safe and ethically responsible, the subject of the following section.

Table 1.2

Sample Preliminary Research Ideas on the Topic "Seeds"

Entity to Study: Seeds
What I could manipulate or change: ☐ amount of sunlight ☐ quality of sunlight (color or opacity) ☐ size or material of container ☐ temperature and humidity ☐ amount of water
What effects I could look for (things to count as well as describe): ☐ seedling growth ☐ speed of germination ☐ # of new leaves ☐ # of leaves per stem ☐ root length ☐ speed of root growth ☐ color of seed, root, stem, and leaves ☐ health of seedlings
Knowledge, tools, and skills I would need to do the project: ☐ How does a seed germinate? What do seeds need to germinate in a controlled environment? ☐ What types of seeds would be good to use for a germination study? ☐ How do I study germination without affecting the root and stem structures? Should I plant the seeds in soil or something else?

Safety and Ethical Issues

Safety Issues

Here at the beginning of the research process, you need to carefully consider the safety and ethical issues involved in conducting a STEM research project. Special safety considerations must be made when working with chemicals, mold and microorganisms, electricity, radiation, and vertebrate animals—including humans. Follow the safety precautions you have learned from your experience in completing laboratory research in your teacher's classroom, but also read up on additional information on safety. You must understand not only a particular safety rule, but also why it is important.

Ethical Issues

In addition to lab safety, you must also consider the ethics of conducting research. Research ethics involve understanding the "norms of conduct that distinguish between acceptable and unacceptable behavior" (Resnik 2010, p. 1). Ethics in the context of conducting research might be something you have never had to deal with on a personal level because the lab experiments your teachers have had you do were chosen so they did not violate any ethical issues.

At universities, however, before researchers conduct experiments, they must receive training and then file certain papers (documentation) with a local Internal Review Board (IRB). University researchers planning to do research with vertebrate animals must receive training and then file documentation with an Institutional Animal Care and Use Committee (IACUC) to be sure that animals will be treated humanely.

Resources for Laboratory Safety

- Hurr, A. K. 2000. *CRC Handbook of laboratory safety.* 5th ed. Boca Raton, FL: CRC Press.
- Flinn Scientific: *www.flinnsci.com/Sections/Safety generalLaboratorySafety.asp*
- Princeton University: *web.princeton.edu/sites/ehs/labsafetymanual/index.html*
- Duke University & Duke Medicine: *www.safety.duke.edu/safetymanuals/Lab/default.htm*
- World Health Organization: *www.who.int/csr/resources/publications/biosafety/WHO_CDS_CSR_LYO_2004_11/en*

The main concern about beginning researchers (such as yourself) is that they are not aware of the issues that may violate the "acceptable behavior" norm. Therefore, there are national regulations put in place to ensure that researchers have thoroughly thought through their experimental procedures, understand the safety and ethical issues, can justify their methods, and can ensure the humane treatment of the entities being studied. Local, state, national, or international fairs and symposia[*] interpret these regulations and provide guidelines for their research participants. Your teacher will provide resources to help you obtain any documentation and committee approval that your experimental design may require for competition.

Even if your project is not being submitted for a competition, safety and ethics must still be considered. Since the Intel International Science and Engineering Fair (ISEF) (*www.societyforscience.org/isef/document*) and the Junior Science and Humanities Symposium (JSHS) (*www.science.siu.edu/ijshs/pdf/ijshs.pdf)* are the largest organizations to host high school state fairs, the guidelines and documentation posted on their websites are excellent models to follow.

If you are working with a mentor in industry or at a university, follow the safety and ethical guidelines set forth by that organization.

Human Subjects as Research Entities

While studying human subjects may be intriguing, procedures must be taken into consideration that protect the rights and welfare of the participants. Most human subject studies require informed consent or assent from the research subjects and IRB approval. Informed consent or assent[**] is the process by

[*] Symposia are formal meetings at which experts discuss a particular topic.

[**] Both *consent* and *assent* basically mean "agreement," but *consent* is used more often in regard to legal matters (e.g., "the age of consent"). *Assent* generally means a positive and voluntary agreement (e.g., "I gave my assent to the plan").

which researchers inform potential study participants about a study and gain verbal or written consent from those participants. If you are asking an individual under the age of 18 to participate, you must also obtain consent from the parent or guardian of that individual.

As you begin writing your proposal in Chapter 5, remember to include IRB committee approval information within the methods section and provide polished versions of consent or assent letters in an appendix to the proposal. Although you need to check regulations in your local area or state, some human subject studies *may not* require IRB approval. These studies may include the following:

- Testing of a student-designed invention, where participant feedback is not personal data and does not pose a health risk.
- Data or record review studies, where preexisting, publically available data sets are used that do not involve interaction with human subjects.
- Public behavioral observations of individuals (e.g., shopping mall, public park) in which all the following conditions apply. The researcher
    - has no interaction with the individuals being observed,
    - does not manipulate the environment in any way, and
    - does not record any personally identifiable data

Other Restricted-Research Entities

Nonhuman vertebrates, human subjects, and potentially hazardous biological agents have specific national regulations that must be followed. Organizers of various science fairs or symposia accept these topics in different ways. Some do not allow high school students to study within these topics at all; others place specific restrictions and require certain documentation. Table 1.3 (p. 12) lists subcategories within a restricted research topic, requirements that may be made by a fair or symposia organization, and alternative project ideas.

Chapter Questions

1. List at least three places you can go to get ideas for your research project.
2. Describe your top three research topic ideas.
3. Focus these three preliminary research ideas into testable questions.
4. How do the safety and ethical issues discussed in this chapter apply to your project idea?

Chapter Applications

Once you have read this chapter, I hope your curiosity will lead you to several research topics. You should have completed Student Handout #1 (p. 14) at least once, if not several times. After completing the handout, you might brainstorm with your classmates and family to improve on the ideas you already have. On the completed handout, begin to jot down various questions using different variations of what you could manipulate and what effects you

Table 1.3

Restrictions, Possible Requirements, and Alternatives for Certain Research Topics

Restricted Research Topic	Possible Requirements	Alternative Topics
Nonhuman Vertebrates • Mammalian embryos or fetuses • Tadpoles • Bird and reptile eggs • Fish • Mammals	• Supervision by a qualified scientist or designated supervisor. • Veterinarian consultation during experiment. • Approval by the Scientific Review Committee (SRC) and/or by the International Animal Care and Use Committee (IACUC) before research begins.	• Do similar studies on other organisms such as algae, ants, beetles, crabs, crayfish, protists, fruit flies, houseflies, lichen, yeast, vinegar eels, slugs, snails, earthworms, planaria, or mealworms.
Human Subjects • Physical activities • Psychological, educational, and opinion studies (e.g., surveys, questionnaires, tests) • Behavioral observations that include interaction, are in nonpublic locations, collect identifying data (e.g., name, date of birth)	• Review and preapproval by the Institutional Review Board (IRB). • If medical information is involved, compliance with HIPAA (health information privacy) regulations. • Risk assessment. • Consent/assent forms for participants to complete. • Supervision by a qualified scientist or designated supervisor.	• Obtain data that are already publically available. • Develop a research design that does not include physical activity or a design that uses data that are anonymous (not able to be linked to a particular participant)
Potentially Hazardous Biological Agents • Microorganisms (bacteria, viruses, viroids, prions, fungi, and parasites) • Recombinant DNA (rDNA) • Human or animal (fresh or frozen) tissues • Blood • Body fluids	• Risk assessment. • SRC and/or IACUC approval before research begins. • Human and Vertebrate Animal Tissue Form (at *www.societyforscience.org.isef*).	• Obtain tissue cultures from reputable biological supply houses. • Use baker's yeast, bacteria, or fungi that are approved by the International Science and Engineering Fair (ISEF) organization. • Use plant tissue, meat or meat products, hair, fossilized tissue or archeological specimens, or prepared fixed tissue.

Source: Adapted from International rules for precollege science research: Guidelines for science and engineering fairs. 2010. *http://apps.societyforscience.org/isef/rules11.pdf* could look for. Remember, the questions need to be narrowed into scientifically testable questions. For example, if you were investigating a topic about microwave emissions from cell phones, you would ask, "How do microwave emission levels vary for new cell phones compared to older ones?" or "What type of cell phone use—calls or texting—emit more microwaves?"

Later, you will modify these questions into a formal hypothesis. Now, however, is the time to explore research topics and possible variations of an experiment. In the next chapter, you will learn the specifics of designing a research experiment. Although you may not have your research topic finalized yet, once you begin developing a research design, you will need an official research topic.

References

Gordon, J. C. 2007. *Planning research: A concise guide for the environmental and natural resource sciences.* New Haven, CT: Yale University Press.

The inquiry process. 2004. Retrieved March 30, 2011, from *http://scene.asu.edu/habitat/inquiry.html*.

International rules for precollege science research: Guidelines for science and engineering fairs. 2010. Retrieved March 16, 2011, from Society for Science and the Public, Intel ISEF document library website: *http://apps.societyforscience.org/isef/rules/rules11.pdf*.

Pedroni, J. A., and K. D. Pimple. 2001. A brief introduction to informed consent in research with human subjects. Retrieved March 17, 2011, from *http://poynter.indiana.edu/sas/res/ic.pdf*.

Resnick, D. B. 2010. What is ethics in research and why is it important? Retrieved March 15, 2011, from *www.niehs.nih.gov/research/resources/bioethics/whatis.cfm.*

Valiela, I. 2001. *Doing science: Design, analysis, and communication of scientific research.* New York: Oxford University Press.

Student Handout #1

Focusing Preliminary Research Ideas

Name ____ Class ___________ Date ______________

Directions: Answer the following questions based on your research interest right now.

1. What entity do I want to study?

2. What could I manipulate or change?

3. What "effects"—that is, things to count as well as to describe—could I look for?

4. What knowledge, tools, and skills would I need to do this project?