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Big Picture Science

The Science Newsletter for Montessori Teachers of 6-15 yr-olds #8 Winter 1999

Guiding Science Investigations

Students need practical advice as they apply the scientific method

Whether they are working on science fair project or other science inquiry, students need practical guidelines to help them learn what they can realistically investigate and how to plan and perform a scientific experiment.

An understanding of the scientific method is an important part of students' education. There's nothing like personal experience to give that understanding. When students do a science investigation, they often pick topics or study methods that are impractical or even unscientific. They can **most use your help in the planning stages** of a science project. Give them a planning form with the steps of the scientific method and a timetable to help them stay on track. They should keep a log of their work.

First, it is important to know that **all science begins with observation and information gathering.** Ernst Mayr, a famous biologist, says that the first question that science answers is the "What?" questions, "What are the components of a system?" for example. The "How?" and "Why?" questions follow. Students need to explore until they know enough about a subject to **ask a good question**. **Good questions are the essence of good science studies.**

Students can gather information from experiment books to get ideas or explore non-fiction literature and Internet sites. Talking to "experts" and personal observations are also valuable. With some subjects, such as astronomy, it may be difficult to take a project past the information gathering stage. The student may be able to make a model and demonstrate one or more related phenomena. (See the example on p. 6.)

Once a student has a good question, it is best to approach experimental planning with the question, **"What are you going to measure?"** All students need to have their focus directed to this question. It belongs on every science project planning sheet. If you can't measure or compare something about it, you can't do a scientific study on it.

It is often easier to measure something in physical science studies. The basic approach of physicists is to simply a system to a few components and measure the effect of changing one of those. Living systems cannot be simplified, so many individual experimental subjects are needed to have a valid life science study. Don't forget the importance of **repeating the experiment**. With physical science projects, three repeats are usually practical. If there is not time to repeat a life science project, take more samples or use more pots of plants, etc. ❖

Let's communicate

Ever since the first Big Picture Science Newsletter I have asked for questions and suggestions from teachers.

I have received a number of positive comments and am very grateful for those.

This quarter I nearly had writer's block on a subject for the newsletter. I'm sure you have subjects you would like to have me address. I welcome your communications on small questions and technical details, as well as larger issues.

If you have e-mail and are willing, send me a brief message so I have your address. I can send group messages (there won't be many) or ask your opinion on newsletter topics.

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Choosing a subject to investigate

The living world. As children begin to select projects, it is helpful to go over a list of subjects available for experiments. It takes a large number of experimental subjects to do a valid life science project. There is always someone who wants to do a project on his or her dog. Experiments involving dogs are not out of the question, provided that the student can find at least 6 (more are better) whose owners would not mind their use. Here is a list of organisms that are feasible to use and some project suggestions.

Bacteria – They are everywhere. You can order special cultures, but they are not necessary. Projects include food preservation by drying, salting, or pickling; making yogurt; making a Winogradsky column to see special soil bacteria (see *Microcosmos Curriculum Guide* from Kendall/Hunt Publishing, 1-800-228-0810). If you wish to order petri dishes of agar medium for culturing bacteria, and if you are familiar with safety procedures, there are studies to sample bacteria on the surfaces, see the effect of a germicidal lamp on skin bacteria, or see how boiling or freezing affects soil bacteria. Petri dishes and living organisms can be ordered from Carolina Scientific Supply (1-800-334-5551) or a local science supplier.

Protists – These are easy to culture from the environment. Projects with protozoa require a suitable microscope. (See *Big Picture Science Newsletter #2* for help.) You can purchase cultures of slime molds, which are easy to grow. See *Creepy Crawlies and the Scientific Method* on p. 5 to find out more. Project ideas – see what protists grow in hay infusions and compare to cultures using other plant material, study how acid rain might effect the organisms in a hay infusion, culture pond algae with different amounts of phosphate and see which grows and survives best. Just identifying the protists from a local pond is a good project, but comparing several ponds adds another dimension.

Fungi – You can buy yeast and culture a variety of fungi from the environment, using common food items or animal dung as culture materials. Caution! Keep mold cultures covered. The spores are highly allergenic and can trigger asthma attacks in some people. Petri dishes (without agar) make useful culture containers, but any container with a clear cover will do. Projects ideas – experiment with a yeast and sugar system (see the box on controls), bake bread and vary the amount of yeast added, find out if very acid foods mold as readily as less acid ones, look for lichens in environments with different levels of air pollution. If you can buy several mushroom culture kits, you can put them at different temperatures or lighting conditions and see if the yields of mushrooms differ

Animals – There are two big categories here, microscopic animals that don't look back at you and macroscopic ones that must have humane treatment. (All projects should show respect to the organisms used, even if some of the conditions are challenging for them. Be sure that the subjects are kept under suitable circumstances. See the references on p. 5 for help.) The tiny ones include roundworms, flatworms, and rotifers. They can be ordered from biological suppliers. "Capturing" and culturing any of these would make a good project. If the student has researched the organism, s/he can hypothesize where the organism might be found and try culturing from several environments, including those where one would NOT expect to find the organism.

There are many larger invertebrate animals that you can get for science studies. Earthworms, crickets, mealworms (beetle larvae), and aquarium snails are often sold for fish bait or pet food. If there are garden snails in your area, they can be used. Be sure to observe where the snails were living when they were captured. There are many interesting studies that focus on trapping insects from the environment. A survey of insects in an area with native vegetation vs. a landscaped location is one possibility. Different trap designs and baits offer others. Exploring the tiny inhabitants of leaf litter and soil with a Berlese funnel is a good project (See *Woods, Ponds, and Fields*, p. 5.)

With these and vertebrate animals, the feasible experiments often involve food preferences and behavior. You can ask if these animals prefer to be in a light or dark area, or what type food they prefer (protein vs. carbohydrate for example). For ideas, see *Creepy Crawlies and the Scientific Method* and *Animals in Action*, (p. 5). NOTE: Wild vertebrates should not be trapped (unless they are released unharmed and a trained wildlife biologist supervises) or brought into the classroom. There is too big a potential for spread of disease from wild mammals and birds.

What about experiments on humans? This is not impossible, but it is difficult to do a valid experiment. Tell your students about double blind studies. When drug manufacturers are testing a new medicine, they have to use this method. This means that the people in the test do not know if they are getting the medicine or the placebo. Further more, the people doing the test cannot know which one they are giving a subject. Doing a double blind test is the only way to get unbiased results. Of course, you can't do harmful things to people. What you can do is measure something about their perception (but NOT their preferences). Taste, vision, hearing, and ability to estimate time are some perceptual things that can be studied. If you have a month or more to do the experiment, a student can measure the growth of several people and see if it follows any pattern. One study showed that children literally grow about a centimeter overnight, rather than gradually increasing. (Continued on page 3)

Choosing a subject to investigate (continued)

Plants – These are readily available, although not all are useful for science projects. Houseplants have been selected to grow in adverse conditions. They may be good leaf donors, but it is hard to show any effect of experimental conditions on them. The best plants to use are young, rapidly growing ones. Any plant that can be grown from seed is suitable. Plant experiments take time. If your time is constrained, sprouts make good experimental subjects. It is certainly easy to get enough of them to do a valid experiment. Another quick idea is to survey the supermarket vegetables to see if the cell pattern on the surface of leaves is the different in monocots vs. dicots. See BPS News #5 for the procedure. Other relatively quick experiments can be done if you have cuttings of a fast-rooting plant, such as coleus or impatiens. Carolina Scientific Supply (1-800-334-5551) sells the Fast Plants system, which uses a small plant from the mustard family that completes its life cycle in about a month. Here's an interesting question. If you grow a tall and a short variety of a plant (marigolds for instance), will the tall variety grow faster or keep growing for a longer time? Or is it some of both? See the sections on bad projects for ideas on what NOT to do with plants.

Physical Science subjects are many and varied. Help students think about the possibilities by listing the main subject areas. Again, the experiment may have to be driven by what can be measured. There are abundant experiment books that cover physical science. See p. 5 for help finding them. Here is a list of topics and a few suggestions.

Light – If you get a good set of colored filters from Edmund Scientifics (1-800-728-6999), there are several levels of experiments to do. For beginners, put colored filters in front of a prism and see what colors of light pass through. Then look through the filters at colored pictures and see how the colors appear to change. Can all colors of light do the same things? More advanced students can test what color or colors of light will "charge up" glow-in-the-dark materials. You know that white light does it, but will separate colors work? Can the student's classmates predict what colors will work?

Optics – includes lenses and more. Investigate the refraction of different solutions and liquids. Use diffraction grating (rainbow) glasses to compare the colors of light from different sources (mercury vapor, sodium vapor, incandescent, fluorescent, and candle light). Investigate polarizing lenses and see how they can be used to find stress in plastics.

Heat – Test insulating abilities of materials. Don't forget to include aluminum foil or other shiny reflector. How fast do different materials transmit heat? A liquid crystal sheet ("Fickle Foam" from Edmund Scientifics) can help students see.

Sound – Demonstrate the Doppler effect. Challenge students to find out what materials insulate sound (It might have great applications when they are teens!) Demonstrate what happens to sound in a vacuum.

Electricity – Batteries from AA to D cells all produce 1.5 volts. So what's the difference? Use each size to power an electromagnet and see how many paper clips it will pick up. What changes if you use two batteries end-to-end? Make your own battery in a jar with copper and zinc strips and vinegar. A small, low voltage buzzer from Radio Shack will help you detect the current. Use a voltmeter for more sophisticated studies. Try some other combinations of metals to how much voltage they produce.

Magnets – If you put a magnet behind a thickness of material, how thick does it have to be to stop the magnetic force? Does the nature of the material matter? You can use iron filings or paper clips to detect the magnetic force.

Motion – This is the category for simple machines, friction, wave motion, and catapults. Flight is a kind of motion and projects can include paper aircraft and, with supervision, model rockets for those about 10 years old and up. See the references on p. 5 for help.

Radioactivity – Something safe that students can do on this subject is build a cloud chamber and see the decay tracks from the thorium in a Coleman lantern mantle. Commercial cloud chambers are available from science supplies. See the Edison book (in references) for help building your own. Can you detect radioactivity from minerals in your chamber?

Chemistry – See Big Picture Science Newsletter #7 for suggestions.

Matter – There are many tests of the properties of materials, including the strength of materials. How much weight will a wooden strip hold if the weight is put on its side vs. its edge? How does the barometric pressure and altitude affect the boiling point of water?

Mathematics and computers – Fractals and chaos theory are interesting newer areas of math that also work well as computer projects. Tilings and geometric patterns are visually and mathematically interesting.

Earth and space science includes weather and climate, solar energy, and soil studies – Model erosion with a stream table. Model the process of tectonic plate subduction and diapirs. Model viscous vs. fluid lavas and find the pressure it takes to move gases through them. Model brittle and deformable sediments with layers of sponge cake and hard icing.

Consumer product testing – There are all kinds of questions to ask. Which paper towel soaks up the most water? Which are stronger, natural or synthetic fibers? The challenge of these projects is in designing the test. ❖

Problem Experiments ... the bad and the ugly

Inevitably when students start thinking about science projects they come up with some ideas that show their misconceptions (the bad) or they ask questions that cannot be answered with the apparatus available (the ugly). Here are some examples.

"I want to see if plants grow better when they hear classical or rock music." This one surfaces frequently. It is an idea that drives me up the wall. The problem is that the student is trying to make a plant into an animal. If students understand plants and understand sound as vibrations of air molecules, then they won't ask this question. It is almost impossible to test, because one would need to have identical growing conditions (same heat and light) in two acoustically isolated places. The control of having no sound is nearly impossible to do.

Other experiments that treat plants like animals include watering plants with things like milk, tea, or soda pop. Instead, have the student learn about the nutrients that plants use. Solutions of the components of fertilizer in various combinations are better choices. If they persist with plans to water plants with people food, they should learn the chemical composition of their test items and how these effect the soil pH and soil bacteria.

The old story of plants growing better when a person talks or reads to them is likely just the result of extra carbon dioxide from the person's breath. Plants do grow better with more of this essential nutrient.

"I want to see how different colors of light affect plant growth." This is a valid idea, but difficult to investigate. The problems lie in getting the same amount of light to each test subject and keeping them all at the same temperature. The results are often ambiguous. If the student is set on this path of investigation, s/he should be aware of these problems. Perhaps using swimming algae, such as Euglena, and projecting a spectrum onto them would be better. The algae will move to the wavelengths (colors) that work best for photosynthesis.

"I want to see if my dog (horse, or other pet) can see colors." This is not a bad question, but it is really ugly to answer. To measure color vision in dogs, researchers had to use sophisticated computer apparatus and measure electrical impulses in the animals' brains. Maybe an experiment to find out how small a piece of meat dogs can smell or how far away dogs can smell a small piece of food might be better. There would have to be a number of cooperative subjects and the investigator would have to carefully remove distracting smells. It wouldn't be easy.

"I want to see if practice improves my computer gaming skill." Well, nice try, but that is not a good question to investigate. Practice improves almost any skill. Perhaps a more valid question would be to ask , "Do people who play computer games have faster reflexes than those who do not?" Be sure to control for age. One way to measure reflexes is to hold a ruler vertically on a table. The subject places his hand at the base of the ruler. The experimenter holds a small object (such as a piece of chalk) at a mark on the ruler and drops it without warning. The subject tries to pull his hand away before the chalk hits it. After several tries from one mark, the experimenter lowers the chalk and continues testing until the subject cannot remove his hand in time. Perhaps the student can program a computer to test reflex time.

Important concepts for experimental design – Positive and negative controls

Studies of the scientific method emphasize the importance of controls. There are actually several types of controls to be considered. Let's take an experiment with yeast and sugar as an example. In this experimental system, we use a suspension of yeast that is all the same concentration and vary the amount of sugar added. We measure the carbon dioxide, CO_2, given off (usually by trapping the gas in an inverted, water-filled container).

There are two important controls here. One is to check the system, using materials that are known to work, to see if we can actually measure what we want. This is the **positive control**. In this system, we can use yeast and grape juice. We know that grape juice supports fermentation. If we cannot detect the CO_2, then our yeast may be dead, our detection system may leak, or the temperature and time may need adjusting. Only when the positive control works can we experiment further.

Equally important is **the negative control**. If we use grape juice or a sugar solution or yeast alone, there should not be a great deal of gas emitted. There may be a small amount just from warming the solution. We can subtract this from our experimental readings.

Now, how do we decide the concentration of sugar to use? We read the grape juice label, which conveniently gives the grams of carbohydrate (virtually all sugars in this case) and check the volume of juice for which the information is given. That tells us grams per ounce and we can convert to grams per milliliter. That's much easier to measure. We can start with the concentration of sugar in grape juice, and then go onto to test fractions and multiples of that concentration. Or we can test other sugars, such as fructose or glucose. (Table sugar is sucrose.) Does halving the yeast concentration affect the result? With these controls, you can actually tell.

Written by Priscilla Spears, Ph.D.

Resources for guiding science experiments

Book resources for science experiments are cataloged under several call numbers in the Dewey Decimal Classification. (If your library uses the Library of Congress system, please see the librarian for help.) Here are some "neighborhoods" to look for specialized topics.

372.3 – science experiment books for teachers
507.8 – general science experiments for students
508 – nature activities
510 – mathematics
520 – astronomy
530 – physics in general
535 – optics
536 – heat
537 – electricity
538 – magnetism
540 – chemistry
550 – Earth science in general
560 – paleontology
570 – life sciences
574 – biology
576 – genetics
577 – ecology
579 - microbiology
580 – plants
590 – animals
600 – the way things work
620 – engineering, materials
621 – simple machines, electronics, computers
628.4 – recycling
641.4 – food preservation
660 – chemical engineering
669 – metallurgy
670 – manufacturing
691 – building materials

Some of my favorite experiment book authors: Robert Gardner clearly explains the science behind experiments on a wide range of subjects. Janice Van Cleave's "___For Every Kid" books are small bites for beginners, but often give little background; her A+ Science Projects series is more advanced and complete. Bernie Zubrowski's books are great, but several are out of print. Robert Wood's "49 Experiments about ___" series is good.

Books referenced in this newsletter:

Barrett, Katharine. 1986. ***Animals in Action***. ISBN 0-912511-10-9 [This is a GEMS (Great Explorations in Math and Science) unit from Lawrence Hall of Science, Berkeley. It gives the Code of Practice on the Use of Animals in Schools from the National Science Teachers Association, as well as good ideas for experiments in animal behavior. Call (510) 642-7771 or go to www.lhs.berkeley.edu/GEMS to get a catalog of other GEMS units. They are designed for traditional classrooms, but many adapt for Montessori use.]

Doherty, Paul and Donald Rathjen. 1991. ***The Exploratorium Science Snackbook***. ISBN 0-943451-25-6. [This has demonstrations that you can build, and is based on the exhibits at the Exploratorium in San Francisco. There are several more books published by the Exploratorium Teacher Institute that would be worth seeking.]

Doris, Ellen. 1994. ***Woods, Ponds, & Fields***. ISBN 0-500-19006-2 [This book has how to make and use a Berlese funnel. It is also published as part of a larger book called ***Big Book of Nature Projects***. They are part of the real kids/real science series from the Children's School of Science at Wood's Hole Mass.]

Kessler, James H. 1997. ***Best of Wonderscience***. ISBN 0-827380941 [This book is expensive – about $50 – but worth it. It has 10 years of activities from *Wonderscience* magazine, an excellent publication for elementary education from the American Chemical Society and American Institute of Physics. The experiments are safe and well explained.]

Kneidel, Sally S. 1993. ***Creepy Crawlies and the Scientific Method***. ISBN 1-55591-118-8 [This is a great guide to experiments with animals and practical use of the scientific method. It tells how to care for slime molds and many invertebrates.]

Sneider, Carl. 1989. ***Experimenting with Model Rockets***. ISBN 0912511206 [Another GEMS unit. See above.]

Thomas Avla Edison Foundation. 1988. ***The Thomas Edison Book of Easy and Incredible Experiments***. ISBN 0471620904. [This has instructions on how to build a cloud chamber for detecting radioactive decay.]

Internet resources

Science Fair project help and planning: <http://www.scri.fsu.edu/~dennisl/CMS/sf/sf.html> This is a good page for ideas and book references. It even has an address to e-mail for help.

<http://www.libertynet.org/lion/internet-by-dewey.html> is a cataloging of sites that index other sites by Dewey Decimal Classification.

The "Mid-Continent Public Library Internet resources in Dewey Decimal Order" is one of the most useful sites for locating Internet sites on science. <http://www.mcpl.lib.mo.us/dewey.htm>

Science fair issues

Do we need to have a science fair? Should it be competitive?

The benefits of science fairs are many. Students may never delve into a topic as deeply as when they are doing a science project. They always learn a lot about how science works and about their topic (with proper parental support). They get a chance to be an "expert" and share their work with the other students and parents. If students carry the expertise they gain into high school, there are scholarships to be won. My science fair project won me significant funding for my undergraduate college education.

Can you turn off students by requiring a science project? I think you can minimize this problem if you start with a subject in which the child is truly interested and help him/her find a reasonable question to ask. There are scientific principles behind virtually anything. It helps if the child is not trying to do a full load of other studies at the same time.

If you do not have judges or awards, the competitive problem decreases. Parents do not feel they must "help" (do the student's work on the project) so much. On the other hand, children want their achievements to be recognized. There is no thrill in getting a participant ribbon, especially if you did a great job and the person next to you did a poor job and received the same ribbon. Here is one suggestion. Give as many ribbons as are warranted (maybe everyone who put out a good effort gets a blue), but make the award specific. Examples: especially good question; creative experimental design; excellent information gathering; attractive display; great conclusions; careful, accurate measuring; good job sharing your findings, or strong effort. One or more of these can be written on the back of the ribbon. The teachers can decide these awards. They may wish to bring in outside science help for evaluating some projects, but a trained scientist will not necessarily know what is a notable effort by a child. Scientist-teacher teams might work well.

What about the child that does a really poor project? It does no one a favor to reward poor work. Perhaps an honest self-evaluation, along with guidance by a teacher and a chance to try again would be the best thing to offer

How do science investigations change at the middle school level?

Middle school students are often uninterested in individual science projects unless the subject is their own personal passion. They may be more interested in a larger, applied, group project that is sponsored by an organization such as the local branch of Audubon Society. If one of your students is really enthusiastic about an individual science investigation, you may need to find a mentor for him/her, as students at this age are able to reach a level of considerable expertise.

Do students always need to do a controlled experiment?

It depends on what they are investigating. For some topics, it may be difficult to find a controlled experiment. I would rather see a student thoroughly explore their interest, even if they can only build a model or demonstrate a relevant phenomenon. You can provide other opportunities to do controlled experiments in class activities.

One thing that helps is to have students demonstrate several related physical phenomena. Here's an example for a lower elementary child who builds a model hot air balloon. Have the child feel around open stove and refrigerator doors to see that hot air rises and cold air sinks. Then show that air expands when it is heated by putting a deflated balloon over a bottle top and setting it in a pan of hot water. Next, model what happens to the air molecules. Use beads or other small round objects to symbolize the molecules. Scatter the beads on a tray and count the number in half or a quarter of it. Explain that molecules move faster and spread apart when they are heated. Spread out the beads, remove some from the tray, and count the number in the same area as before. This sequence helps the child understand why the air is less dense and rises when heated, and how hot air balloons work.

How can I get students to focus on the measuring aspect of their project?

One way is to ask them to make a graph of one or more sets of data. If they lay out a potential graph before they do the experiment, they may spot problems with their plans for data collection. They will at least focus on the units they need to measure. If they were unable to collect numerical data (there are few instances where one cannot), they can still come up with a graphical representation of categories such as "turned redder". This helps them realize that they can measure something even if they are not collecting numbers.

What is the scientific method anyway? You will find many definitions. Seymour Simon defines it as "a way of investigating questions by pursuing facts and fitting them into current theories or creating new theories to fit new facts". This is a good overall definition. The steps of the scientific method vary with the investigation and investigator. Scientists don't always follow a rigid procedure. In general, there has to be information gathering, asking a question or forming a hypothesis (an educated guess about what will happen under certain conditions), doing an investigation to test the hypothesis or help answer the question, and then concluding something from your findings. Sometimes the conclusion is that you don't have enough evidence to find the answer. Most investigations have follow-up questions. Communicating your findings is an important part of the process.