Connections: Investigating Reality[*] and Science

Some mistaken assumptions: *Science is a body of knowledge that must be memorized by students. The way to teach and learn science is to put the information in a textbook, have the students read it and listen to teacher-talk about it, and give them tests to find out how much they remember. The more information put into the book, the more effective it becomes.*

These assumptions structure most science courses at primary and secondary levels, but science education based on these false assumptions is bound to be ineffective. An old Chinese proverb tells the main truth: "Tell me and I will forget, show me and I may remember, involve me and I will comprehend." *Involve*, in the case of science education, means getting back to science's roots: learners performing experiments to discover information for themselves.

Science courses used to do more of this, but those false assumptions listed above have led educators to believe in the necessity of "covering the material," and the amount of material to cover has expanded year after year, so the hands-on aspects of science education have been discarded as inefficient use of class time.

The weight and bulk of textbooks have reached a point where they intimidate most students. "You mean I have to learn all that stuff?" is their natural reaction when confronting one of today's thick and heavy science textbooks the first time, and it is no wonder that so many of them have little enthusiasm for what follows. Almost certainly there is an inverse relationship between the size of the book and the amount of that information that kids retain from it a year after the course is completed.

"Covering the material" is a waste of time if learners haven't comprehended in depth what they're reading about. Just because the textbook has a clear explanation written in simple language (accompanied by suitable illustrations) of kinetic energy, photosynthesis, or tectonic plates doesn't mean that learning will occur. If our goal is helping the learner understand science, the learner's role must be more than passively reading and listening, then going through tests of short-term memory. For real in-depth learning, there is no alternative to active involvement of the learner in the processes of looking at reality, questioning, investigating, and communicating results—in other word, *real* science. Second-hand versions of reality taken from textbook pages simply fail to communicate effectively for many, perhaps most students.

Using reality as the primary learning resource has multiple advantages, besides the increased involvement that leads to deeper, more lasting learning. Dealing with scientific aspects of the learner's own environment increases the likelihood that the learner will view what is being learned as relevant. Involvement of the type we're advocating is self-motivating. And asking questions of reality requires exercise and development of complex thought processes, not just memorization.

Science is, more than anything else, a process: asking questions about aspects of reality, and working to find answers. The first goal of science courses should be to develop within learner's minds this questioning (perhaps even skeptical) attitude about information that they receive, along with the willingness to check things out for themselves. Present-day science courses designed to convey masses of facts are simply contrary to scientific thought.

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[*] Note that *Connections: Investigating Reality* has been renamed ***Introduction to Systems***, and some of these investigations are now incorporated. See http://www.marionbrady.com/IntroductiontoSystems.asp

***Connections: Investigating Reality* (*CIR*) is, among other things, a science course, fostering questioning attitudes and investigative processes. Applying the analytical systems concepts presented in *CIR* (environment, components, interactions, motive forces) to what is being studied will organize the information within any science course, even the traditional textbook-based ones. A systems approach can bring order to the chaotic mix of information that fills many textbooks.**

Those focusing on science may feel the need to include more traditional science content. To that end, we are providing additional investigations that may augment or replace the investigations included in *CIR*. And we are open to creation of other, similar investigations prepared by others. Our guidelines for science investigations:

1. Whatever is being investigated must be a readily-accessible part of the learner's own reality. There are myriad science investigations that can be based on what can be observed within the limits of the school property. If necessary for some investigations, this area could be expanded to include the community or the surrounding, accessible territory, of course.
2. Investigations should be complex enough to challenge learners without overwhelming them. The best investigations will result in some surprises, even for the teacher.
3. The investigations should be, as much as possible, directed by the learners themselves. As we stated in *CIR*, our experience indicates that small groups are most productive in performing investigations.

On the pages that follow are two sample science-centered investigations of the sort we'd like *CIR* users to generate and pass along to us for publication. We'll give full credit and recognition to those who generate these investigations, of course.

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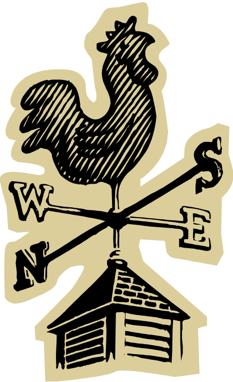
Investigation: Patterns in Weather Fronts



Investigate patterns in changes of temperature, wind speed, and wind direction as a weather front approaches and moves through the area. Show results of your investigation in graphs, and write an explanation of what you've observed.

Thermometers to measure air temperature are readily available, of course, and identifying wind direction is easy, so long as you know cardinal directions (north, east…etc.) for your location.

Wind speed can be estimated by observing its effects: http://weather.about.com/od/imagegallery/ig/Weather-Map-Symbols/Beaufort-Wind-Scale.htm

You may choose to build devices for indicating wind direction (a weather vane) and for measuring wind speed. Some homemade devices are described on the Internet.

A simple cardboard or thin metal rectangle, approximately 70 x 150mm, suspended from a rod (e.g. coat hanger wire) by bent paper-clip pivots on one end so it can swing freely, may be used to measure approximate wind velocity. When held so the rod is perpendicular to the wind direction, the vane will swing up at an angle proportional to wind velocity.

Attach a scale to the rod beside the vane to indicate the vane angle and wind speed. Paper clip or clamp weights may be necessary on the bottom edge of the vane to keep it from being too sensitive. The device may be calibrated for speeds up to, say, 25 MPH, by holding it out the window of a slow-moving car. Use the front window, and hold the device out far enough to avoid the extra wave of air near the car, compressed by the car's motion. Note that the scale will be non-linear.

Notes for teachers/mentors:

As with many investigations, the time spent on this will depend on the extent of student interest, and the level of hands-on participation (e.g. if learners make their own weather instruments, the investigation will take more time, but the amount of real learning that occurs will be enhanced). The investigation should continue so long as significant learning is occurring; it could, of course, continue as “background” activity while other investigations are going on.

Note that a great deal more is being learned besides the nature of weather fronts. For example, participating in the investigation will help enhance the basic attitudes of science, and measuring, graphing and reporting the results will link science learning with math and communications skills. (Erasing the artificial boundaries between courses and disciplines is one of our goals.)

The first step, in most situations, is identification of the cardinal directions with some precision. Local or municipal maps will likely be the main resource for this information. If the exercise can be extended to a starry night, setting up markers pointing toward Polaris (if visible) may provide a reasonably-accurate north reference line.

Interesting point for discussion: If you only investigate a single weather front, are you identifying *patterns*?

Include discussion of possible problems in measurement, e.g. effects of nearby objects and proximity of the ground in altering wind speed, the errors caused if direct sunlight falls on a thermometer, etc.

Investigation should include identifying the orientation of the front. For example, in Florida, winter cold fronts are generally oriented southwest to northeast as they move in from the northwest. Wind switches to the south and southwest (parallel to the front) in the hours before the front passes, temporarily bringing in warm air. Then the clouds and rain pass through, and the wind switches, coming from the northwest behind the front, bringing cold air, clear skies, and higher barometric pressure.

Alternative:

An easy web-based version of this exercise is to simply record the information at regular intervals (e.g.15 minutes) from a local weather station that transmits this information.

The National Weather Service provides 3-day history at one-hour intervals for weather stations in the United States. (http://forecast.weather.gov) This information may be copied and graphed to show the changes. Note that the Internet gives you access to weather stations anywhere in the United States, so data for weather fronts from different locations may be compared. If National Weather Service data is used, learners can even record data and compare weather front data from the same weather front as it passes two or more different locations, as well as keeping records to compare two or more weather fronts..

One interesting extension is an early lesson in calculus—plotting the *rate of change* in temperature (degrees per minute or hour) as the front moves through.

Investigation: Sun Angle and Solar Heat

Build a solar thermal sensor:

Materials: Small dial-type kitchen thermometer (0° to 220° F or 0° to 100° C)

Corrugated cardboard

Thin sheet aluminum, 100 mm square (flattened metal from a cut-up soft drink can or throw-away pie pan will work)

Flat black paint (liquid or spray)

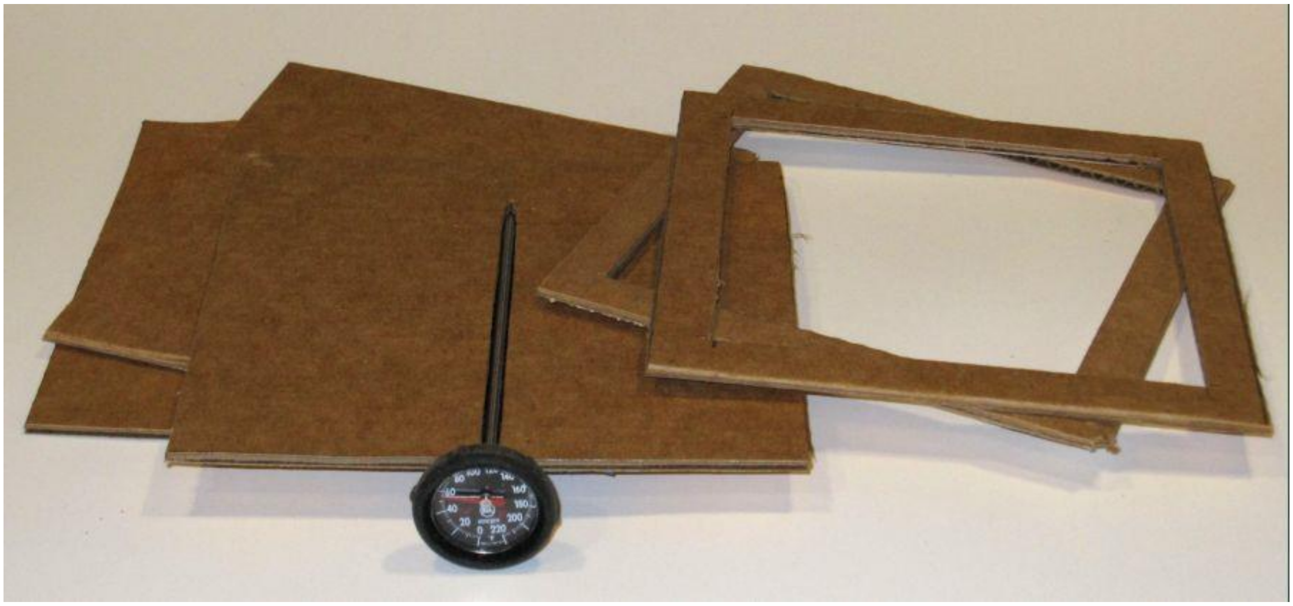
Masking tape & glue

Transparent food-wrapping film (such as Saran Wrap®)

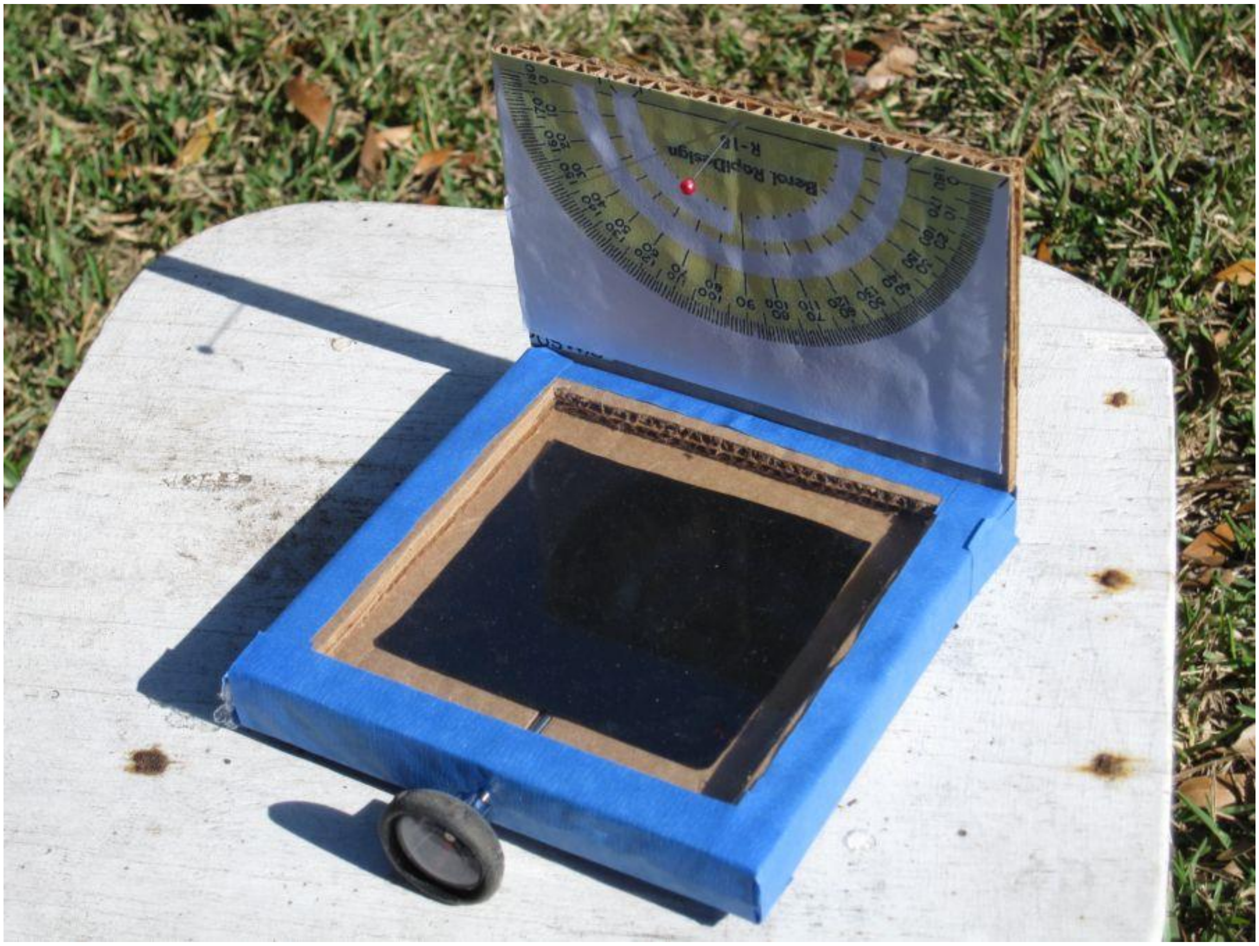
Straight pin

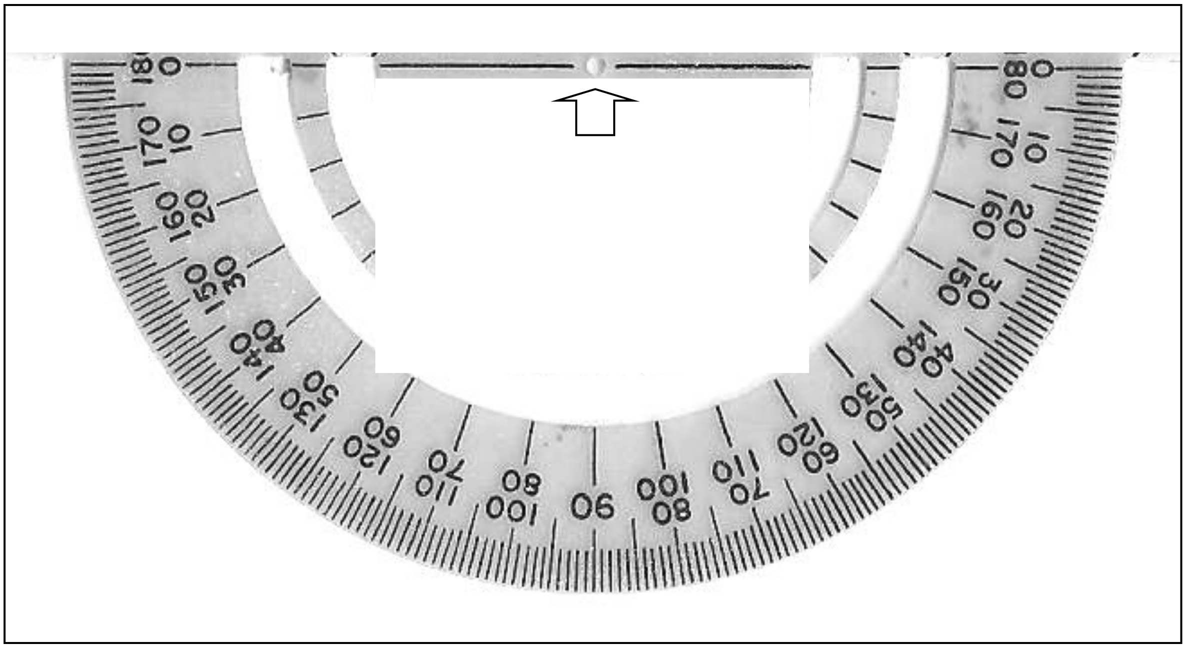
Assembly Procedure:

1. Cut out and flatten the aluminum to make a square, each edge 100mm long, and paint one side flat black.
2. Cut out five 150mm squares from corrugated cardboard.
3. On two of the squares, mark lines 15mm in from each edge, and cut out the centers to form frames.
4. In a third square, cut a narrow slot for the stem of the thermometer, as shown.



5. Glue the squares together in a stack, with the two plain squares on the bottom, the square with the thermometer slot in the middle, and the two frame squares on the top.
6. When the paint on the aluminum square is dry, glue or tape it inside the frame, centered against the thermometer stem slot. If you use tape to hold the aluminum down, use small pieces of transparent tape just at the corners.
7. Cover the outside top with transparent film to make a window, and hold the film in place with tape. (The film helps minimize effects of air movement.) Put tape around the edges of the heat sensor, to help hold it together.
8. Copy the protractor image on the next page, and mount it as shown to indicate sun angle. Insert a pin at the center, perpendicular to the surface, to make a shadow. In this photo, the sun angle is about 33°.





Print this page, and cut out the rectangle containing the protractor.

Cut a rectangular piece of corrugated cardboard, 100mm x 150mm. Make sure the two long sides are parallel, by measuring the rectangle's width at each end. The two width measurements should be identical.

Place the protractor so the top edge is precisely parallel to the edge of the cardboard and glue it in place.

Mount the cardboard to the sensor box as shown in the photograph.

Insert a pin at the center, where the arrow points to the image of a hole. Make sure the pin sticks out straight, perpendicular to the surface.

Sunny Day Experiments:

Note that these experiments should be done on a clear, sunny day when the wind is still or gentle, and the outdoor temperature is not changing significantly, probably between 10 AM and 3 PM. If the wind is strong, find a sunny spot that is shielded from the wind by a building.

1. ***Place the sensor in the shade, and allow its temperature to stabilize to ambient (i.e. the surrounding air temperature). Record this temperature.***

2. ***Place the sensor in the sun, and prop it so the sun angle is 90°. Make sure the sensor is aligned so the edge of the protractor is pointed directly toward the sun. Allow the temperature to stabilize, which will take a few minutes. Record this temperature.***

3. ***Reset the sensor so its face is precisely level with the ground, similar to the photo on the previous page. (For extra precision, use a small carpenter's level to check that the sensor top and the top of the protractor are truly level, and make sure the edge of the protractor is aligned toward the sun, as indicated by its shadow.) Record the sun elevation angle.***

4. ***Allow the temperature to stabilize, and record the temperature.***

5. ***Repeat the measurements, propping the sensor at other sun angles, recording the angles and the stabilized temperatures. At minimum, measure and record temperatures at sun angles of 30° and 60°, in addition to the 90° reading obtained in step2, and the local horizontal reading (step 3).***

6. ***Subtract each sun-generated temperature from the ambient temperature measured in step 1, to find the temperature rise (ΔT) at each sun angle.***

7. ***Repeat step three above at local solar noon (i.e. when the sun is at its highest point in the southern sky, if you are in the northern hemisphere). Make sure you measure the sun angle above horizontal as precisely as possible. Note that solar noon will likely be different from "clock" noon.***

8. ***Wait a week or two, and measure the solar noon sun angle again, as you did in step 7.***

Summary:

9. ***At the time of the measurements in steps 7 and 8, is the sun's angle increasing or decreasing from day to day? How fast is it changing? Why is it changing?***

10. ***Make a graph showing the relationship between sun angle and temperature rise.***

11. ***Make a diagram showing the relationship between sun angle and latitude, assuming the sun is directly overhead at the equator.***

12. ***What do your results suggest about the relationship between latitude and temperature? Between sun angles and the seasons of the year?***

13. ***Make diagrams showing relationships between sun and earth at summer and winter solstices. Describe in words the meaning of each diagram.***

Investigations prepared by Howard Brady, January 2011.

Description of *Introduction to Systems* (course materials, replacing *Connections: Investigating Reality*): http://www.marionbrady.com/IntroductiontoSystems.asp

Notes for teachers/mentors:

Some years ago, an investigator, accompanied by a video cameraman, went to the commencement exercises at Harvard University. Immediately after the ceremony, the investigator questioned a number of those standing around in their caps and gowns, asking them, “What causes the seasons of the year?”

Most of those questioned were unable to provide an accurate answer. The majority view was that “the sun is closer to the earth in summer.”

No doubt they had “covered” the subject of seasonal variation and the axial tilt of the earth several times in their scholastic careers, beginning in the lower grades. This incident points up the lack of effectiveness of passive forms of education. Simply reading a principle or hearing it described fails to make much of an impression on most learners. The sun angle investigations suggested here are much more likely to result in real learning that will “stick” in the minds of the learners.

As might be expected, the solar energy (per unit of area, e.g. square centimeter or square mile) incident on a surface at an angle to the sun’s rays is proportional to the sine of the angle of incidence—maximum at 90°, falling to half of that maximum at 30°. This change in solar energy per unit of illuminated/heated area is the reason for seasonal changes in temperature.

The underlying reason for the seasonal variation in sun angle—the 23.4° tilt of the earth’s axis with respect to its orbital plane around the sun—is difficult to investigate “direct from reality.” If the sun angle measurements were to be continued over a period of six to nine months to find the local maximum and minimum noontime sun angles, the difference will be 46.8°, (double the tilt angle of the earth’s axis), and the mean value (i.e. the noontime sun elevation at time of equinoxes) will be equal to 90° minus the local latitude. Thus, for Washington, D.C., 38° N. latitude, the highest sun angle (about June 21st) will be 75.4°, the lowest noon sun angle (about December 21st) will be 28.6°. The noontime sun angle at the vernal and autumnal equinoxes will be about 52°.

Note that as an alternative to using the solar protractor on the collector to identify changes in sun angle over a period of time, the tip of the shadow of a tall object (e.g. flagpole or the corner of a roof) may be measured or perhaps marked with a dot of paint. If a tall object is used, and the measurement is made at solar noon, the change in sun angle from one day to the next can be detected. The change, of course, would be difficult to detect around the times of the solstices, when the day-to-day change is low.

A note about "noontime:" Local *solar* noon occurs when the sun is at its highest elevation above the horizon, when the sun is within a few degrees of south, for locations in the northern hemisphere. This will differ from "clock" noon, because of geographic location within time zones and variations such as daylight savings time. The time of solar noon also varies significantly with the time of year, because the earth's axial tilt affects the geometry of the sun's apparent motion across the sky. For more information: http://www.solar-noon.com/

Additional possible questions/activities for learners:

- When the sensor is placed in the sun, why does the temperature stabilize instead of continuing to increase? (Answer: When equilibrium is reached, heat losses balance heat gains. The main loss is through re-radiation of heat from the absorber. Other losses are from cooling due to imperfect insulation, and because the black-painted aluminum reflects some of the sun's energy instead of absorbing it.)
- Find the local latitude on a map, then calculate the noontime sun angles for the solstices and equinoxes. (90° minus the local latitude = sun elevation at vernal and autumnal equinoxes; add and subtract 23.4° from this value to find sun angles at summer and winter solstices.)

Additional note: The wrong assumption on the part of many learners that "in summer we're closer to the sun" is at least in part due to learners not appreciating the scale of the distance between the earth and the sun. The sun, at 93 million miles, is far enough away that the variation in distance due to the tilt of the earth's axis is insignificant. Due to the eccentricity of the earth's orbit about the sun, the whole earth is actually a bit closer to the sun during the northern hemisphere winter than during the summer.

Expansions—suggest that learners:

1. Build and calibrate a sundial.

2. Learn a bit of trigonometry: Use the protractor to measure sun elevation angle, then immediately measure the horizontal length of a shadow of a tall object (e.g. flagpole). This gives the necessary information to calculate the object's height, using the formula:

$$\tan \alpha \cdot d = x$$

…Where α is the measured sun angle, d is the shadow length, and x is the unknown object height. Note that in measuring the shadow length, learners must be careful (if the ground around the object is not flat), to make sure the shadow length measurement is truly horizontal.