Introduction to Systems* and Science†

Some mistaken assumptions: Science is a body of knowledge. Educating is a matter of "covering the material"—transmitting that knowledge to students by way of text or teacher talk. Tests measure the percentage of information learners can recall after the passage of some (usually established) interval of time.

These assumptions structure most science courses at primary and secondary levels, but science education based on these false assumptions is bound to be ineffective. What is supposed to be 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 understand." *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 an inefficient use of class time.

The weight and bulk of textbooks have reached a point where they intimidate and discourage many students. It should come as no surprise that many have little enthusiasm for the subject. Almost certainly there's an inverse relationship between the size of the book and the amount of information from the book that can be recalled a few weeks or months later.

"Covering the material" is a waste of time if learners haven't really understood what they're reading or hearing. Too often, kids will underline and memorize key sentences in textbooks or lecture notes, recognize the sentences or phrases from the sentences when being tested, and answer questions correctly, exhibiting a skill that has little or nothing to do with understanding.

For real in-depth learning, there's no alternative to active learner involvement in looking directly at some aspect of reality, poking, prodding, questioning, testing, analyzing, describing, communicating conclusions. That's *real* science. Second-hand versions of reality taken from textbook pages simply fail to communicate effectively for many, perhaps most students.

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* Formerly *Connections: Investigating Reality*. See http://www.marionbrady.com/IntroductiontoSystems.asp

Using the real world as the primary learning resource doesn't just increase the likelihood of deeper, more lasting learning. Dealing with the learner's immediate environment increases the likelihood that the focus of study will be seen as relevant, learning will be self-propelling, and learners will require and develop complex thought processes.

Science is, more than anything else, a process: asking questions about aspects of reality, and working to find answers. The first goal of science instruction should be the development of curiosity about how the world works, a degree of skepticism toward common suppositions and "facts," a willingness to check things out, and tools and strategies for doing so. Science instruction that inundates learners with "canned" information is counterproductive. Activities such as those suggested here help learners exercise the processes of science; once these have been adopted, "covering the content" (an impossible task) can be downplayed. If learners need particular science information in the future, they have the tools to acquire it.

Introduction to Systems (IS) is, among other things, a science course, encouraging questioning attitudes and investigative processes. Applying the analytical systems concepts presented in *IS* (environment, components, interactions, motive forces, system change) to what is being studied will organize the information within any science course, even traditional textbook-based ones. A systems approach can bring order to the chaotic mix of already-processed information in most textbooks.

Those focusing on science may feel the need to include more traditional science content. To that end, we're providing additional investigations that may augment or replace the investigations included in *IS*.

We're open to adding similar investigations designed by others. Our guidelines:

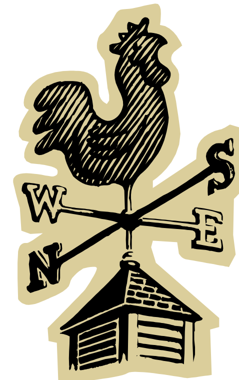
1. Whatever is being investigated must be a readily-accessible part of the learner's own reality. Myriad science investigations can be based on what can be observed on school property. If necessary or desired for some investigations, this area could be expanded to include surrounding, accessible territory.
2. Investigations should be complex enough to challenge learners without overwhelming them. The best ones may result in some surprises, even for the teacher.
3. The investigations should be, as much as possible, undertaken by learners themselves, with minimum adult intervention. As we say in *IS*, our experience indicates that small work groups or teams are most productive.

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

The final section includes a list of suggested team projects in science—potentially a year of science augmentation to *Introduction to Systems*. We welcome additional suggestions. Contact Marion Brady / Howard Brady

Note: The practical math activities at https://www.marionbrady.com/IntroSystems/Systems-Math.pdf are useful preliminaries to any science activity.

Investigation: Patterns in Weather Fronts



Investigate patterns in changes of temperature, wind speed, wind direction, clouds, and precipitation as a weather front approaches and moves through the area. Show results of your investigation in graphs and photos, 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: [Beaufort scale - Wikipedia]

You may choose to build devices for (1) indicating wind direction (a weather vane), (2) measuring wind speed (anemometer), (3) barometric pressure (barometer), (4) temperature (thermometer), (5) rain gauge, etc. Homemade devices are described on the Internet.

A thin metal rectangle (e.g., flattened aluminum from a soft drink can or throw-away pie plate), 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 will 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 or 40 KPH, by holding it out the window of a slow-moving car. Use the front window, and hold the device out far enough and high 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. 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 basic attitudes toward science, and measuring, graphing and reporting the results will link science learning with math and communications/language arts skills. (Erasing the artificial boundaries between courses and disciplines is one of our goals.)

In most situations the first step is identification, with some precision, of the cardinal directions. 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 (along with an astronomy lesson that will likely be new to many learners).

Question 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 (and most of eastern United States), 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. This will have less impact, of course, than direct outdoor measurements. **If at all possible, frequently-collected temperature data and estimates of wind velocity and direction, at minimum, should be**

observed directly by learners, since many weather stations only update information every hour.

The National Weather Service provides 3-day history at one-hour intervals for weather stations in the United States. (https://www.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 time interval, e.g., hour) as the front moves through.

Tying all of this information-gathering back to the basic systems concepts (environment, components, interactions, motive forces, system change) is an important part of the learning process. As with every investigation, this relating process is best done by the learners; the teacher/mentor's role is to generate careful questions. The main motive force is, of course, sunlight; its effect on weather and climate is central to all else, and is the focus of the next activity.

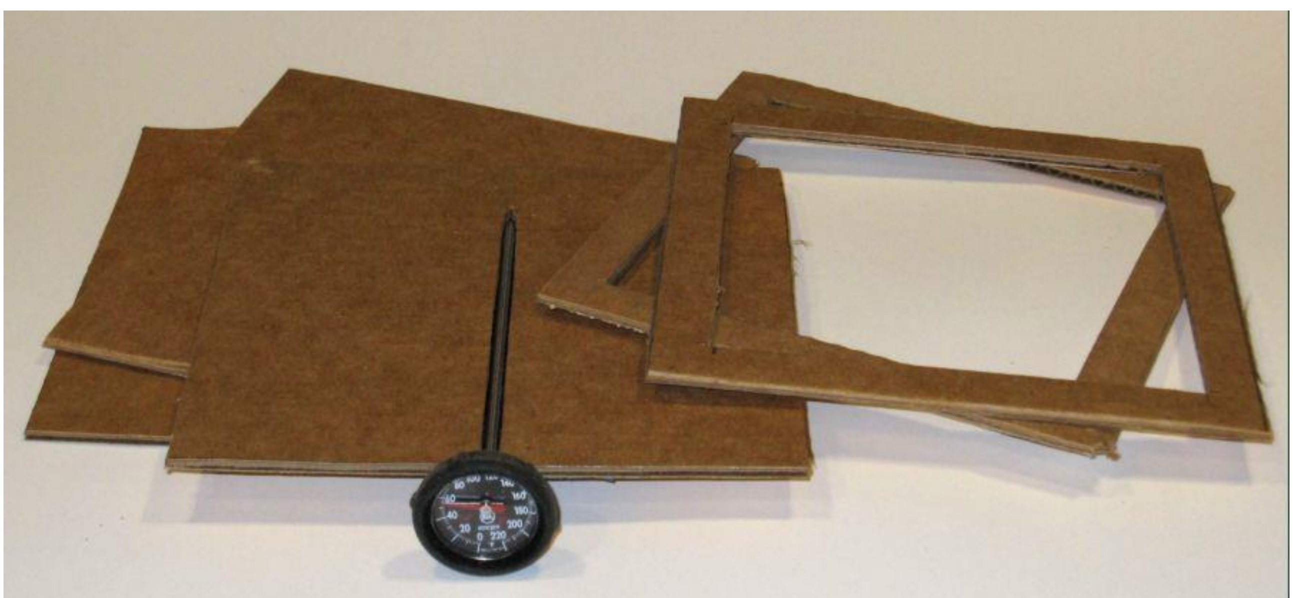
Investigation: Sun Angle and Solar Heat

Build a solar thermal sensor:

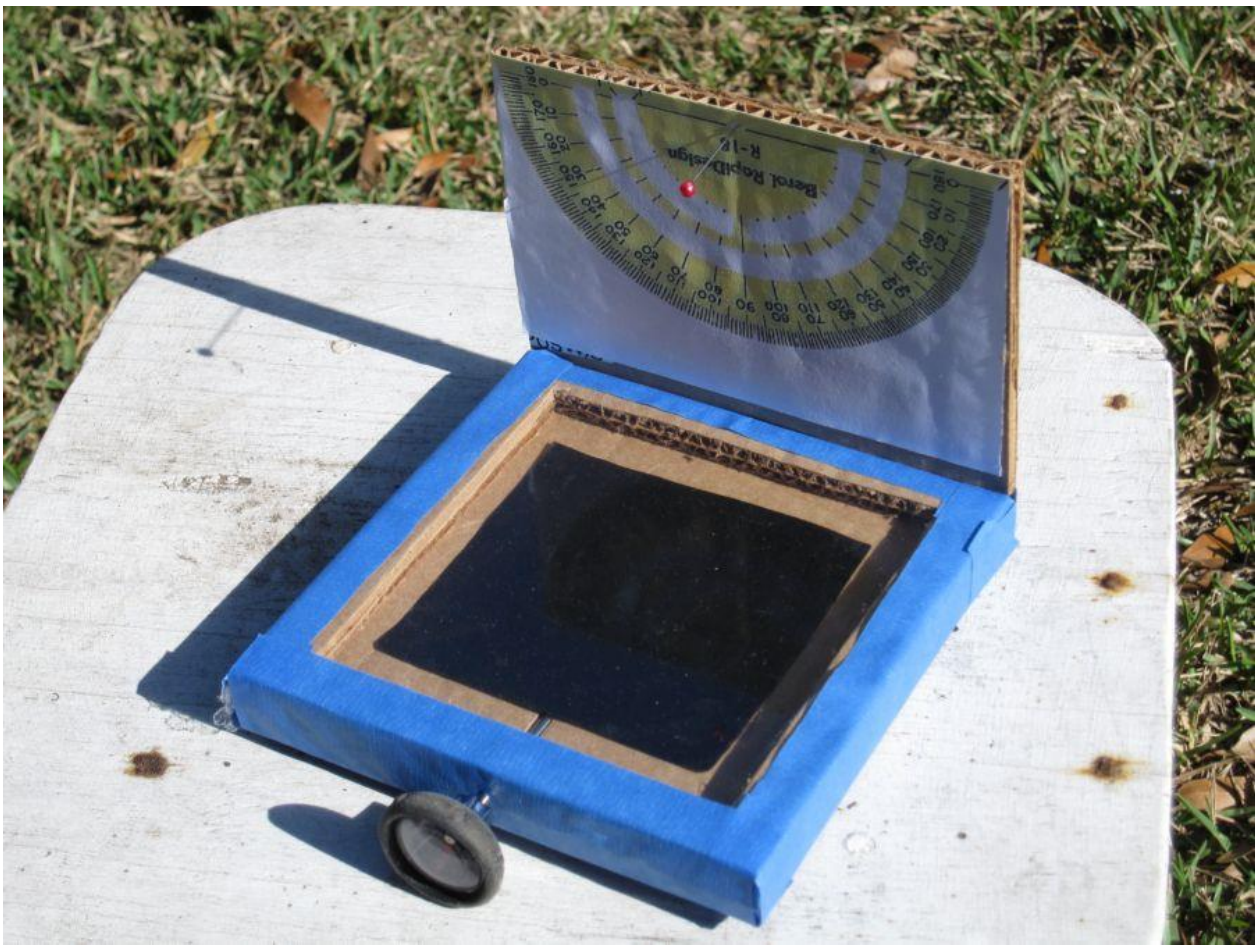
Materials:
Small dial-type kitchen thermometer (0° to 220° F or 0° to 100° C)
Small, short carpenter's bubble level
Corrugated cardboard
Thin sheet aluminum, 100 mm square (flattened metal from a cut-up soft drink can or throw-away pie pan will work)
Flat black paint (liquid or spray)
Masking tape & glue
Transparent food-wrapping film (such as Saran Wrap®)
Straight pin

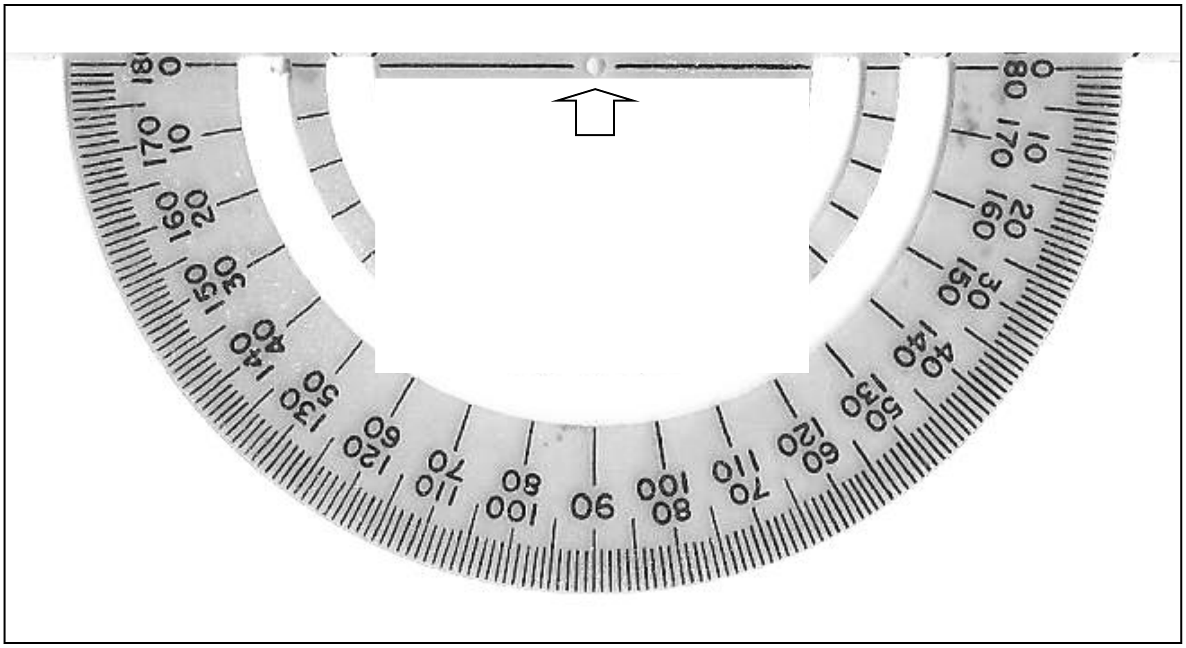
Assembly Procedure:

1. Cut out and flatten the aluminum to make a square, each edge 100 mm long, and paint one side flat black.
2. Cut out five 150 mm squares from corrugated cardboard.
3. On two of the squares, mark lines 15 mm 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° above horizontal.





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 with little or no wind, and when the outdoor temperature isn't changing significantly (probably between 10 AM and 3 PM). If the wind is strong, find a sunny spot that's shielded from the wind by a building or wall.

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 step 2, 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 to 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 (ΔT).
11. Make a diagram showing the relationship between sun angle and latitude, assuming the sun is directly overhead at the equator.

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*Δ (Greek letter "delta") is often used in science to indicate a difference between two values.

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.

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—*angle*, not distance, causes seasons.

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 = maximum sun elevation at vernal and autumnal equinoxes; add and subtract 23.4° from this value to find maximum sun angles at summer and winter solstices.)

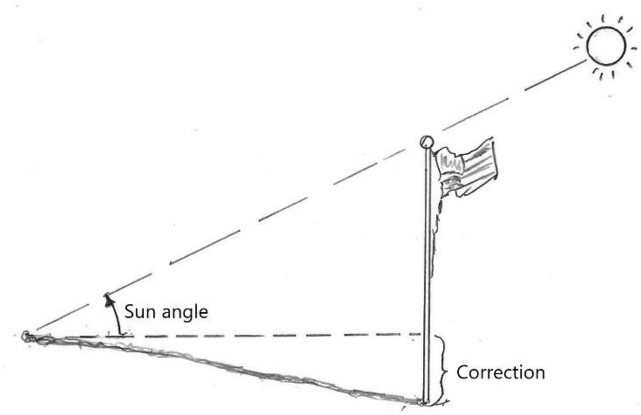
Additional note: The wrong assumption on the part of many learners that "in summer we're closer to the sun" is at least in part due to learners not appreciating the scale of the distance between the earth and the sun. The sun, at 93 million miles, is far enough away that the variation in distance due to the tilt of the earth's axis is insignificant. Due to the eccentricity of the earth's elliptical 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 both the protractor top and the shadow length measurement is truly horizontal. If the shadow tip is above the level of the bottom of the object, the difference in elevation of these two points must be added to the calculated height.



Science systems projects

We suggest small groups, each focusing on a different area of interest, e.g.

Weather
Astronomy
Aerodynamics
Mechanical engineering
Botany/Biology
Electricity
Robotics, rocketry, etc.

To the greatest extent possible, work groups generate their plans and conduct their own investigations, prepare reports and present findings to the class, followed by question-and-answer session from other class members. Main organizing tool for investigations would be the system model on Part 2, page 5 of *Introduction to Systems* https://www.marionbrady.com/IntroSystems/2AnalyzingSystems.pdf.

Possible systems for science-related investigation:

Earth science—Local geology: Collection (with documentation of location—photos, maps, etc.) of rocks and identification of type (limestone, sandstone, etc.)

Soil types, variation in types of native plants with soil and other influences.

Typography: local drainage patterns (rate of stream flow vs. terrain, with variation in type of path (straight vs. sinuous, etc., use Google Earth® for aid). Tracing runoff of local precipitation. Water-borne components: Rocks, pebbles, sand, silt—Sequence of sedimentation vs. water velocity (experimental). Find water table levels (wells, etc.). Percolation, evaporation rates. Pollution levels in local streams/rivers.

Mapmaking/surveying…compass, pacing off distances, measuring angles, etc.

Solar system/astronomy (limit to just earth, sun, moon for main investigations):

Create a model of the simplified solar system with tilted earth axis, and track polar seasonal extremes, seasonal variations in day/night length, etc. This can be an extension of the "Sun angle and solar heat" investigation (page 6).

Add moon to model, to demonstrate relationship between appearance (phase) of moon and relative position of sun and earth (full moon rises at sunset…), and variations in appearance across the lunar month (quarter moon, new moon, etc.), and relationships between bodies during eclipses.

Identification of major constellations, stars and planets.

Weather systems: Patterns, seasonal and daily variations, cloud types and precipitation determined empirically, air pressure variation and weather, wind direction and weather, fronts, etc. Note investigation of weather fronts, and suggestions for learner-built weather instruments, page 3.

Existence of air pressure (use vacuum cleaner to pull air out of cardboard box—it collapses…why?).

Plot frequency of weather extremes over time.

Biology: Application of the Model elements to living systems (environment, components, etc.) Insects as systems (functions: eat, reproduce, life cycles…) Predator & prey. Cell growth & division. Protists in grass infusion. Local birds, rodents, and other wildlife. The human body as system; analysis of sub-systems of human body.

Botany: Plant systems (several initially-identical plants grown from seeds in water…?) What's in the system? What is not? (Light, air, etc.) Variables: temperature, light, air (closed small glass container?). Classification/taxonomy of plants (similarities/differences, which variations are most important, principles of grouping using dominant characteristics, growth patterns, propagation, etc.)

Identify and catalog every kind of plant growing on school property (photos, etc.).

Plant growth in various substrates: Cotton wool, sand, potting soil, etc. Effect of various amounts of light; Tropism—attempted sideways growth? Necessity of air (CO_2) (Need way of testing?); Photosynthesis investigations.

Chemistry: Solution/crystallization, simple reactions, basic electrochemistry (breakdown of water into H_2 & O_2, gas rate production vs. voltage/current applied to system, copper plating, simple batteries), acid/bases/pH, chemical and physical characteristics (e.g., specific gravity) of readily-available elements (iron, copper, zinc, lead, etc.), distillation, crystallization.

Physics: Much of physics can be introduced as integrated components of, e.g., earth science, rather than as abstract principles.

Forces and effects: Centrifugal, gravity, pressure, velocity, acceleration, inertia.

Simple machines: lever, wedge, screw, inclined plane, pulley, wheel/axle. Possible: Learners document examples of each in real life with photos.

Heat, friction, states of matter, evaporation, etc.

Siphon, air thermometer, pendulum (see *IS* part 2, page 8; https://www.marionbrady.com/IntroSystems/2AnalyzingSystems.pdf).

Sound and vibration, transmission through air, frequency vs. physical characteristics such as length of vibrating string, human ability to detect relationships in sound frequency. Musical intervals—octave, fourth, fifth. Building musical instruments (whistle/flute, cigar box guitar, etc.).

Light: reflection, refraction, dispersion, prisms, lenses, images, focal lengths, relative apertures.

Aerodynamics: Paper airplanes as systems. Build wind tunnel (Fan and tube), conduct measurements of drag and lift of various forms. (This will require some way to measure small forces.)

Production line for paper airplanes (made from old newspapers), compete in flying at least 6 feet when pushed from table height…as many planes as possible in X minutes. (Note that the production line becomes a system.) Include quality control in production.

Simple electrical systems, component approach to investigating system elements (e.g., flashlight) Concepts: Conduction/resistance, insulation, circuits, energy conversions: (chemical to electrical, mechanical/magnetic to electrical, electrical to magnetic/mechanical, reversal of all conversions), batteries, voltage & current, magnetism, static electricity, capacitance, inductance. Circuit construction techniques (wire stripping, soldering, etc.).

Mechanical engineering: Create a system: Tinker Toy® or other mechanical system project with goal… e.g. With no external energy input during timed demonstration, make something that will keep rotating/moving as long as possible…. e.g., weight-driven, wound-up string (team competition?) Analysis of mechanical systems in common devices (e.g., automobiles, farm/yard machinery, appliances).

School/home systems: Electrical, plumbing, HVAC, sewage, trash, food supply, appliance technology, etc. See investigations on page 19 of Part 4 of *IS*: https://www.marionbrady.com/IntroSystems/4DemogrSetting.pdf

Lots of ideas for experiments are available on line: Search for "fun science experiments." Use the systems Model concepts to analyze each experiment and its results.

Description of *Introduction to Systems* (course materials): http://www.marionbrady.com/IntroductiontoSystems.asp

Added suggested projects: HLB 11/2021