YEAR of the SOLAR SYSTEM
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Theme: ***Gravity: It's What Keeps Us Together***

Gravity-Induced Tides: It's What Pushes Us Apart

An Excellent Example of the Process of Scientific Inquiry

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Recommended Classroom Use of this Material

The materials relating to gravity, tides, the slowing of the Earth's rotation, and the confirmation of the accuracy of radiometric age dating techniques make an engaging supporting story for ***high school level Earth Science classes studying radioactivity and age dating of geologic materials.*** The story is doubly useful in that it also ***showcases the process of scientific inquiry and the reciprocal linkage between scientific and technological advances***.

The story works both as a stand-alone reading assignment (followed by class discussion), or as a teacher-guided set of questions (teachers can pose the same questions posed in the story, and guide the subsequent discussion along the lines of the text). Supporting props, such as balls when discussing apparent size as functions of actual size and distance, can greatly assist the learning process.

Alignment of This Topic with Standards of Scientific Learning

The "coral cross-check" story illustrates aspects of the process of scientific inquiry and the synergistic link between scientific research and the technology that enables it, two topics that often are difficult for teachers to address without additional learning aids. Both topics appear in many State science learning standards in one form or another.

Example 1: Radiometric age dating techniques are explicitly included in the McRel compendium, Science Standard 2 ("Understands Earth's Composition and Structure"), Topic ("Earth's History"), Level IV (grades 9-12), Benchmark 5 ("Knows methods used to estimate geologic time (*e.g.*, observing rock sequences and using fossils to correlate the sequences at various locations; using the known decay rates of radioactive isotopes present in rock to measure the time since the rock was formed).").

In addition to the inclusion of radiometric dating as an explicit content item, the McRel standards also allow for the independent testing of the validity of the radiometric dating technique via scientific inquiry cross-checking. An illustrative example is the McRel compendium Science Standard 12 ("Understands the nature of scientific inquiry"), Level IV (high school), Benchmark 3 ("Evaluates the results of scientific investigations, experiments, observations, theoretical and mathematical models, and explanations proposed by other scientists (e.g., reviewing current scientific understanding, using evidence to validate conclusions, examining the logic to determine which explanations and models are the best, examining the involvement of control groups, examining the adequacy of the sample)," particularly "using evidence to validate conclusions."

Example 2: The reciprocal link between science and technology is articulated explicitly in the McRel Standards compendium for Technology by Standard #3 ("Understands the relationships among science, technology, society, and the individual") Topic, "Science, Technology, and Society," Level III (grades 6-8), Benchmark 4 ("Knows that technology and science have a reciprocal relationship (e.g., technology drives science, as it provides the means to access outer space and remote locations, collect and treat samples, collect, measure, store, and compute data, and communicate information; science drives technology, as it provides principles for better instrumentation and techniques, and the means to address questions that demand more sophisticated instruments)."

Many States have similar standards of learning relating to the relationship between scientific inquiry and technological development. An example: District of Columbia Public Schools, Grade 6, Standard 6.2.2: "Explain that technology is essential to science for such purposes as measurement, data collection, graphing and storage, computation, communication and assessment of information, and access to outer space and other remote locations."

The Coral Cross-Check Story

An Example of the Process of Scientific Inquiry and the Reciprocal Relationship Between Science and Technology

Tides in the Earth's oceans, caused by the gravitational pull of the Moon and the Sun, cause large-scale movements of water. In some places, electricity is produced commercially from tidal movements of water. Tidal movements (flexing) also occur within the Earth, and similarly within the Moon, generating heat and seismic activity.

But where does the energy for all that activity come from?

The answer: The rotation of the Earth. Tidal forces/friction within the Earth, and more importantly, movement of water in the Earth's oceans, dissipate the energy associated with the Earth's rotation very slowly (in other words, the day is getting longer, since the day is defined as the time taken for the Earth to rotate once).

The total angular momentum of the Earth-Moon system remains essentially constant during the slowing of the Earth's rotation, but only because the Earth-Moon distance increases, thereby increasing the contribution to total angular momentum from the Moon's movement along its orbit, to offset the reduction in total angular momentum caused by the slowing of the Earth's rotation.

The rate at which tides slow the Earth's rotation and cause the Earth-Moon distance to increase was conceptualized centuries ago (some credit Immanuel Kant in 1754), but accurate estimates of the size and rate of those changes could not be made until gravitational theory and observational technology were developed sufficiently. Full observational confirmation did not occur until technology had advanced enough to allow the placement of laser reflectors on the surface of the Moon and the development of sufficiently precise distance-measuring techniques utilizing those reflectors.

What Might Be the Consequences of These Changes Be?

Some of the consequences of the day and month lengthening are curiosities only. One such arises from the fact that the Moon and the Sun have almost the same apparent size as seen from the Earth. The Moon's orbit is slightly elliptical; when it is nearer the Earth than average, the Moon appears slightly larger than the Sun, when it is farther away, the Sun appears slightly larger than the Moon. Total solar eclipses can only occur when the Moon is closer; if the Moon is farther away it is not large enough to cover the entire face of the Sun, leaving a ring ("annulus") of sunlight. As tides force the Moon farther from the Earth, annular eclipses will become more commonplace and total eclipses more rare. Eventually, in a few hundred million years, Earth will enjoy no further total solar eclipses at all.

Another consequence of the slowing of Earth's rotation is <u>much</u> more significant: *It provides excellent, independent corroboration of one of the most important of the geologist's tools, the use of radioactive decay to determine ages accurately over very long time periods.*

In hockey, "cross-checking" is a foul that will get you a stint in the Penalty Box. But in the inquiry process or the courtroom, and of the laboratory, cross-checking in the form of independent corroboration is highly desirable! Courtroom testimony backed by other eye-witnesses, and/or by video, photo, fingerprint, DNA, or other independent evidence, is much stronger than one person's story by itself. The same is true in scientific inquiry.

Can anyone think of examples of how corroboration helps make a claim believable?

"Radiometric dating" is the determination of the age of an object based on the relative quantities of radioactive material and its decay products present in that object, and the rate at which radioactive decay occurs. Different radioactive materials have different decay rates, and are hence used for specific age ranges. For example, carbon-14 has a half-life of a few thousand years, so the familiar C-14 dating techniques can only be used on objects that are at most a hundred thousand years old or more. That is adequate for most anthropological studies, but not adequate for most geologic materials, which are thousands of times older. Decay sequences involving radioactive versions of potassium, rubidium, uranium, and other elements are employed to determine the ages of the older materials.

One form of corroboration, internal consistency, is met for radiometric dating, when different decay sequences and rates produce the same age for the same sample, but regardless of the specific radioactive material used for dating, the technique requires that the decay rates to remain constant over the age of the sample. While observations spanning many decades show no measurable change in any decay rate known, it would strengthen the confidence in the radiometric dating method in general of some sort of age corroboration could be found that did not use radioactive decay *at all*.

Here comes the part about gravity, tides, the slowing of the Earth's rotation, and the increasing Earth-Moon distance. The latter two provide a two-step example of the process of scientific inquiry

Scientists have known for centuries that the Earth's rotation rate had to be slowing down and the Earth-Moon distance had to be increasing, both due to tidal forces. Those rates could be calculated with considerable accuracy, but were very, very small, too small to be measured directly with the prevailing technology of the times. However, ***predictions*** of those rates could be and were made, even if they could not be measured with adequate precision to confirm or dispute them.

How might we measure the Earth-Moon distance precisely?

Apollo astronauts left behind on the Moon several sets of mirrors aimed back at Earth. Lasers, shot through large telescopes at those reflectors, bounce back to Earth and can be detected. The time taken for the laser light to go to the Moon and back can now be measured with astonishing precision needed to allow the growth in the Earth-Moon distance to be observed directly. Such measurements have ***confirmed*** the prediction for the increasing Earth-Moon distance due to tides.

Similar technological advances also allowed the ***predicted*** increase in length of Earth's day to be ***confirmed*** by direct observation.

Therefore, step 1 of the scientific inquiry process is complete. Thanks to new technologies that allow radiometric ages to be determined precisely, and that allowed reflectors to be placed on the Moon, we now have observational confirmation of the predicted rates of the slowing of Earth's rotation and the increase in the Earth-Moon distance predicted by calculating tidal forces.

What value might there be in knowing the rate at which the Earth's rotation is slowing?

If we know the rate at which the Earth's rotation rate is changing, then we can calculate the rotation rate, and hence length of day, for any time in the past or future. Since the length of the year, the time taken by the Earth to orbit the Sun once, is not changing, there were more days per year in the past when the Earth was spinning faster.

Trees add a "growth ring" each year, and the size of that ring provides clues to the climate conditions that particular year. Specialists have used wood from very old trees to derive a chronology covering the past 8000 years or so; given a fossil log from, say, an archaeological site, they can often place its lifespan to the very calendar years that tree lived.

But trees are not the only living things that have growth rings! Some types of shells have obvious annual growth rings, a fact known since the time of Aristotle, because the rings were readily visible to the unaided eye. It turns out that many corals and shell-forming animals secrete a thin growth layer every day, but those thin layers remained unknown until microscope technology advanced enough to make them visible.

So shells and coral can have daily growth rings, so what?

The thickness of tree rings is a reflection of the growing conditions prevailing in that particular year of growth. Similarly, the thickness of the daily growth layers in shells and corals also depends on growth conditions, which in this case is largely the warmth of the water in which the coral, etc. lived, which is, of course, in turn affected by the time of year. If the view of the coral/shell cross-section could be magnified enough, one ought to be able to see a year-long cycle of thickness variations in the stack of daily growth layers, and hence be able to count directly the number of days there were in the years when that coral/shell was alive. This tactic could provide a cross-check on radiometric dating; the coral/shell would have ages determined by radioactive decay and by the days/year ratio at the time of life, two techniques completely independent of one another!

John W. Wells of Cornell University recognized the potential for using the Earth's slowing rotation rate to provide corroboration for radiometric dating, even before the slowing was confirmed by direct observation. His measurements of growth rings in fossil corals, published in 1963, yielded a year length of 385-410 days. The Earth's rotation rate, extrapolated from the present value using the observed slowing rate, indicates an age of ~380 million years for those corals, plus or minus 30 million years or so. The corals came from a geological formation adjudged to be from the Devonian Period, with a radiometric age of 380 million years!

Thus ended Step 2 of the initial scientific inquiry. **Radiometric age dating had independent corroboration**, but scientific inquiry is not a static process. Subsequent investigations have not only confirmed and refined Wells' results, but have developed *sclerochronology,* the study of astronomical cycles recorded in shell, coral, and other hard tissues, analogous to dendrochronology of trees*,* into an important scientific sub-discipline dealing with paleoclimate and paleoenvironment studies.

Selected Sources of Additional/Amplifying Information

Wells, J.W., 1963, Coral growth and geochronometry, *Nature*, v. 197, p. 948-950

Knutson, D. W., Buddemeier, R. W., and Smith, S. V., 1972, Coral Chronometers: Seasonal Growth Bands in Reef Corals, *Science,* v. 177, p. 270-272.

Williams, G.E., 2000, Geological constraints on the Precambrian History of the Earth's Rotation and the Moon's Orbit, *Reviews of Geophysics*, v. 38, p. 37-59

Selected links to on-line information on sclerochronology:

- http://www.coral.noaa.gov/research/climate-change/sclerochronology.html
- https://www.floridamuseum.ufl.edu/envarch/research/methods/sclerochronology
- https://pubs.usgs.gov/pp/2007/1751/professional-paper/tile2/sclerochronology.html
- https://repository.si.edu/bitstream/handle/10088/7734/00220.04.pdf?sequence=1&isAllowed=y