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Technology in introductory geophysics: the high–low mix

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Abstract

Geophysical concepts are challenging to teach at introductory levels because students need to understand both the underlying physics and its geological application. To address this, we are upgrading an introductory course with a mix of 'high' and 'low' educational technology. The primary focus is 'low' technology, using class demonstrations and experiments to demonstrate underlying physical principles and their geological applications. We integrate these into the course, together with the 'high' technology of computer simulations and the vast resources of the World-Wide Web, using a course webpage (http://www.earth.nwu.edu/people/seth/B02). The 'high'/'low' mix provides students with different representations of the same concept. We hope that by using both methods, we help students to better visualize concepts from class. Simulations and demonstrations also serve as a break from a steady diet of equations and make the class more fun for instructors and teaching assistants to teach. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

There has been much attention devoted to improving earth science curricula. In our effort, we began by taking a 'faster, cheaper, better' approach to upgrade our introductory geophysics course (Stein and DeLaughter, 1997). To make our course livelier and to make the concepts more memorable, we developed 'low-tech' class demonstrations and experiments to better illustrate the underlying physical principles of topics presented in lecture. We now integrate these into the course, together with the 'high' technology of computer simulations and the vast resources of the World-Wide Web, using a course webpage (Klosko et al., 1998). We implement a mix of 'high' and 'low' technology to present students with different representations of the same concepts, to supplement class lectures. Recently, these ideas were brought together with others conducting similar efforts, using the Internet and multimedia to improve earth science education, at the August 1998 NSF/AGI workshop for the Assessment and Dissemination of Web-based Education Materials in the Earth Sciences.

Our geophysics course is highly rated; it is required of geology students and also taken by engineering students. The course provides a relatively rigorous and homework intensive overview of the structure and evolution of Earth and terrestrial planets, at a higher level than a descriptive introductory class, but at a lower level than the standard introduction to geophysics class for advanced undergraduates and first year graduate students. For example, in this class we typically present without proof results such as Snell's Law and the heat equation, which will be derived in more intensive courses.

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2. 'High' tech links: course webpage highlights

A course webpage (http://www.earth.nwu.edu/people/seth/B02), leads the class to a wealth of geophysical information available from the World-Wide Web. For each topic covered in class, the course page contains basic class information (syllabus, textbook reading assignments); homework problems (real data and selected readings from Internet links); and laboratory/in class exercises (computer simulations and 'low' tech demonstrations). There are also supplemental links on the course webpage mostly from the Internet, which include ongoing research (e.g. space missions, seismic tomography, space geodesy), virtual field trips (e.g. San Andreas, Iceland, Tibet), and biographies of famous scientists who contributed to understanding these topics.

3. 'Low' tech demonstrations

Our 'low' technology class and lab demonstrations provide simple analogues for complicated concepts, to clarify topics from the course. Demonstrations are chosen that are inexpensive, easy to set up and take down, and which can be conducted in a standard classroom that is not set up for laboratory experiments. Descriptions of the demonstrations are listed on the course webpage and they are given in class, at weekly lab meetings, and as homework assignments, to go along with topics in the course.

4. 'High' versus 'low': which works best?

There are strengths and weaknesses to either 'high' or 'low' tech methods. For example, a 'high' tech method for demonstrating Snell's Law is the use of a interactive computer simulation (Fig. 1A). The approach shows light beams penetrate various media (e.g. vacuum, water, corn syrup). For geophysical purposes, the simulations are limited, as they do not include important effects. For example, amplitudes and critical angle phenomena are not demonstrated, because they typically are not programmed in the simulations. Another approach is to present Snell's

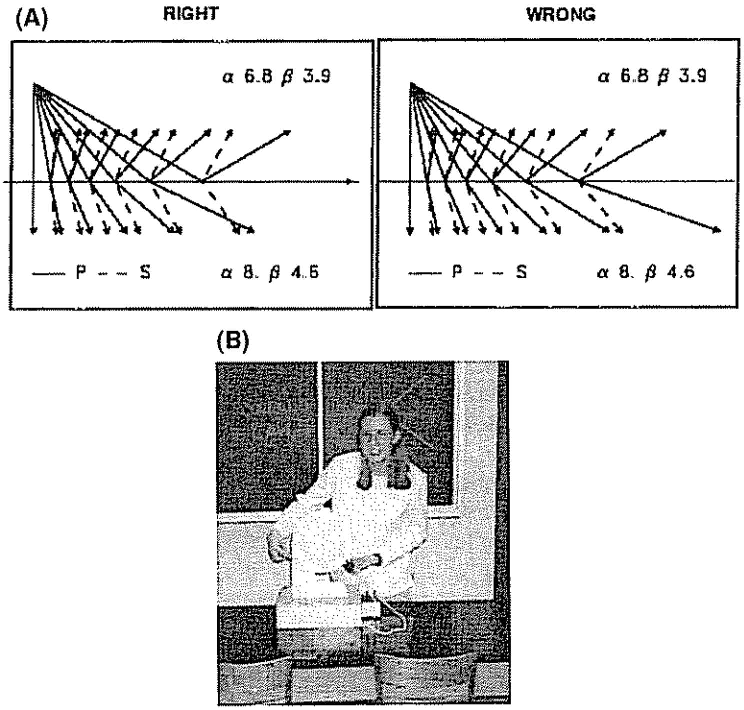

Fig. 1. (A) Computer simulation of Snell's Law (left): $\sin(i)/v$ = constant, and an incorrect formulation of law (right): i/v = constant. Computer simulations are useful for demonstrating various phenomena, but work equally well in demonstrating the wrong principle! (B) Snell's Law presented as a 'low' tech demonstration by Sarah Wilkison, using light beams in tank with protractor back, whose upper and lower parts contain air and water. This apparatus physically displays Snell's Law (from the angles the beams make) and other important concepts for geophysics such as angle dependence of reflection coefficient (from beams' brightness) and head waves occurring due to total internal reflection.

Law via a 'low' tech demonstration (Fig. 1B), using light beams in a tank with a protractor back, whose upper and lower parts contain air and water. This demonstration physically displays Snell's Law (from the angles the beams make), the angle dependence of the reflection coefficient (from the beams' brightness) and head waves (occurring due to total internal reflection).

In general, a benefit to 'low' tech demonstrations is that many of today's students have not conducted or even seen (or equivalently, have seen and forgotten) once-standard experiments demonstrating many basic ideas of classical physics used in geophysics. Demonstrations obey physical laws, whereas, computer simulations work equally well even when the basic underlying principle is wrong (Fig. 1A). Computer simulations are limited to what they are designed or programmed to show, whereas demonstrations are more versatile. On the other hand, computer simulations can illustrate a broader range of geological phenomena, conditions, and time scales (e.g., plate motions and mantle convection). Thus, by combining both 'high' and 'low' tech methods, we can attempt to exploit the benefits of each.

This mix of 'high' and 'low' tech demonstrations, listed by topic, include:

4.1. Seismic waves

We demonstrate aspects of seismic wave propagation using largely standard means. A block of foam rubber with a grid is used to illustrate the bulk and shear moduli. As mentioned previously, light beams in a tank with a protractor back, whose upper and lower parts contain air and water, display both Snell's law (from the angles the beams make) and the angle dependence of the reflection coefficient (from the beams' brightness). We do a number of the standard wave (ripple) tank demonstrations for basic wave propagation, and local variants including using a cylindrical obstacle as a 'core' about which diffractions can be seen. We insert an acrylic slab with metal bolts into the tank to show the concepts of Huygens' principle, point diffractors, exploding reflectors and focusing of energy by a synclinal structure ('bow-tie' effect). P- and S-wave particle motions are illustrated with the classic 'Slinky' and by rubber bands stretched over the open side of a plastic box. The latter demonstration is particularly useful because it shows how the wave speed depends on the tension (adjusted by stretching the rubberband) and density (adjusted by attaching paperclips to the band). The idea of using travel times to infer structure is demonstrated using an inexpensive electronic (acoustic) distance measurement device to find the room's size.

We also use some computer simulations which reinforce concepts, showing features more clearly than we have been able to do with demonstrations. We illustrate a number of wave propagation ideas, including the effect of multiple reflections and transmissions, via a normal-mode simulation of waves on a string with an internal boundary (Geller and Stein, 1978). We show a video simulation of seismic waves in a realistic earth model, which demonstrates the relation between the seismic wave field and specific wave phases (e.g., ScS) (Wysession and Shore, 1994). To illustrate the problem of under-sampling, we watch the title sequence of 'The War Wagon' (many other Westerns would work) on video, and note that as the stagecoach speeds up, its wheels appear to rotate backwards! We use a 'Virtual Earthquake' exercise on the Internet (from California State University, Los Angeles, http://vquake.calstatela.edu/edesktop/VirtApps/VirtualEarthQuake/VQuakeExecute.html) for earthquake location and magnitude determination.

4.2. Gross structure of earth and solar system

We find Earth's mass from the acceleration of gravity by two methods: a ball drop using a commercial timer and photogate system, and timing several swings of a pendulum. (The pendulum method, which was pioneered by Galileo, works as well or better than the more modern electronic method.) Racing a hoop and disk of the same mass down an inclined plane motivates the concept of moment of inertia, and leads to the idea of using a planet's moment of inertia to learn about its core density. When discussing solar system formation, we demonstrate conservation of angular momentum using a string connecting two balls threaded through a hole in the base of a cup (Fig. 2). We set the upper ball swinging, so as the lower one

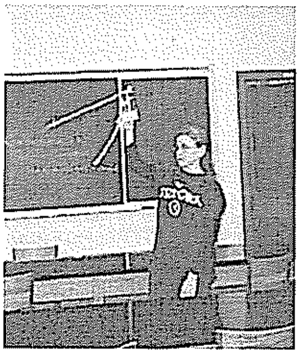

Fig. 2. Conservation of angular momentum is demonstrated using string connecting two balls, threaded through a hole in the base of the cup. Shown here is Eryn Klosko using this apparatus that she set swinging, so as lower ball slides down, radius of top ball's orbit decreases and speeds up.

slides down, the radius of the top one's orbit decreases and it speeds up. We combine these demonstrations with Internet links on the course page to NASA missions (e.g., Mars Pathfinder, http://marsweb.jpl.nasa.gov/; Near Earth Rendez-vous, http://huey.jpl.nasa.gov/~spravdo/neat.html), real data (e.g., Planetary Fact Sheet (from NASA, http://nssdc.gsfc.nasa.gov/planetary/planetfact.html)), and virtual field trips (e.g., The Nine Planets; A multimedia tour of the solar system, (by Bill Arnett, http://www.ece.nwu.edu/~pred/TNP/nineplanets/))

4.3 Understanding earth's interior

A dipole magnetic field is illustrated using a commercially available clear plastic box filled with iron filings in oil, into which a magnet is slid (this works nicely on a overhead projector). We then use a dip needle to illustrate Earth's field. To demonstrate convection simply, we put a clear beaker containing water and miso soup (which provide tracers) on a hot plate, and let it heat up. With proper lecture pacing and some practice, convection begins just as the Rayleigh number discussion reaches the appropriate point. Using Internet links to convection 'movies', (from the University of Queensland, http://shake2.earthsciences.uq.edu.au/~winter/convect.html) we ask the class to describe conditions in the earth that lead to high and low Rayleigh numbers.

We illustrate the effect of atmospheric pressure by having students attempt to pull a standard plunger off a desk, and then consider pressures thousands and millions of times greater. We pour water into a detergent bottle with holes drilled at various depths, so the obvious difference in water flow demonstrates the increase of hydrostatic pressure with depth (Fig. 3). Half-frozen apple juice illustrates fractional crystallization, and the presumed partitioning of elements between the inner and outer cores, when the class tastes the difference in sugar concentration between the solid and (sweeter) liquid. We use a 'web-movie' that simulates the growth of a 'core' which shows the idea of the inner core 'freezing' to form the outer core. The relation between cooling rate and crystal size is illustrated by heating crushed moth balls and crayons in test tubes until they melt, then cooling the tubes at different rates (placing one in an ice bath and one in the air).

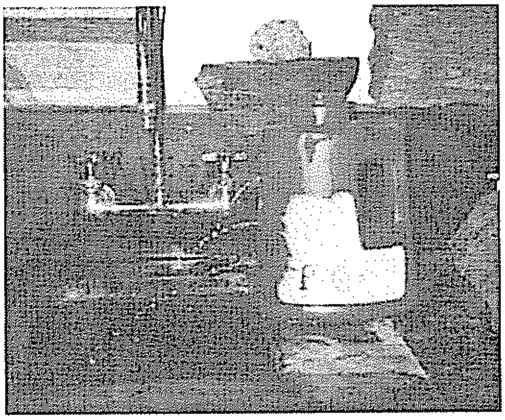

Fig. 3. The variation of hydrostatic pressure inside Earth is demonstrated with a detergent bottle with holes drilled at various depths. Once the bottle is filled with water, difference in water flow, shown here, demonstrates an increase in pressure with depth.

4.4 Plate kinematics

We demonstrate a number of ideas central to plate kinematics using paper cutouts, following the spirit of Cox and Hart (1986). The cutouts nicely explain the often tricky concept of transform faults, and the relation between relative plate motions, rotations about Euler poles, and plate boundary types. A cutout of the Pacific–North America plate boundary zone in a Mercator projection about the rotation pole lets students watch the boundary evolve and see how this single boundary contains ridge, transform, and subduction portions (Fig. 4). An additional feature of paper cutouts is that they make great homework problems, and provide a sense of the history of plate tectonics. We use an Internet link to a plate motion calculator (from the University of Tokyo, http://manbow.ori.u-tokyo.ac.jp/tamaki-html/nuvel1.html) to determine the relative motion of plate pairs (based on the NUVEL-1 model, (DeMets et al., 1990)). We use other links for virtual field trips to the San Andreas Fault (from Stanford University, http://sepwww.stanford.edu/oldsep/joe/fault_images/BayAreaSanAndreasFault.html) and to the Mid Atlantic Ridge (from Woods Hole Oceanographic Institution, http://www.ocean.washington.edu/education/magic/1page/index.html). We also simulate triple junction evolution, and do simple past plate reconstructions. Absolute plate motions can also be demonstrated, using a pencil as a 'mantle plume' and moving one piece of paper (simulating a plate) over a fixed one (simulating the mantle) (Stein, 1997). To provide 'real-life' examples of hotspots, we use Internet links for virtual field trips to Hawaii (from USGS, http://vulcan.wr.usgs.gov/Volcanoes/Hawaii/Locale/framework.html), Iceland (from Pangaea Scientific, http://pangaeasci.com/_iceland.htm) and Yellowstone (from USGS, http://vulcan.wr.usgs.gov/Volcanoes/Yellowstone/images.html).

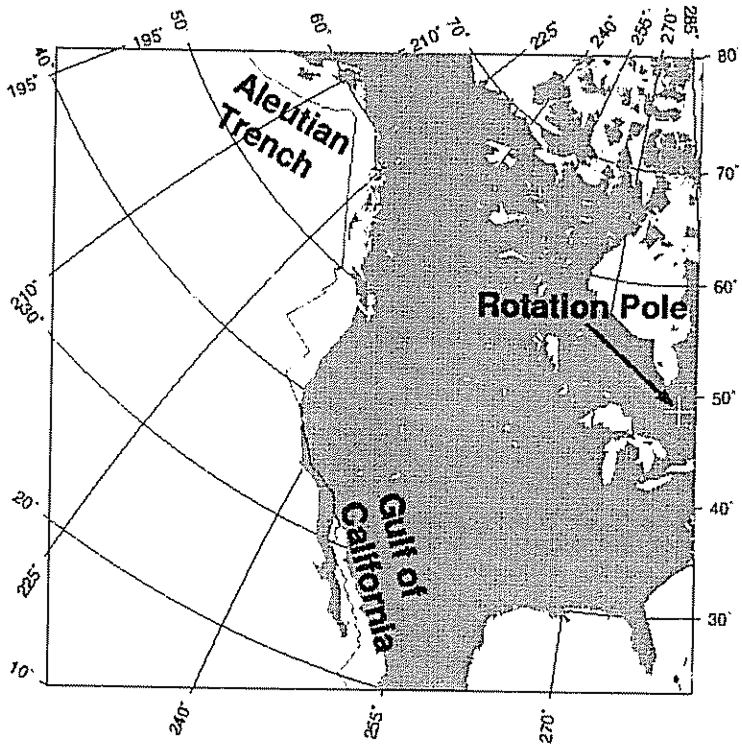

Fig 4 Oblique Mercator map of Pacific–North American plate boundary zone Cutting along the plate boundary and rotating North American plate counter-clockwise about its pole (280°E, 48°N), demonstrates how this single boundary contains ridge (Gulf of California), transform (San Andreas Fault) and trench (Aleutian) portions

4 5 *Radioactive decay*

We use a 'web-movie' of radioactive decay to simulate the concept of parent elements decaying into daughters, and half-life (Fig 5) From the animation, the students can compare the numbers of parent versus daughter atoms to estimate the amount of time since a sample was created We also simulate radioactive decay using toothpicks, where students are given an equal number of plain and colored toothpicks and a box with a marked side Starting with all the plain toothpicks in the box, students shake it up and replace all plain toothpicks pointing to the marked side with the colored toothpicks By recording the number of plain and colored picks in the box for each trial, students can see how the decay curve is generated and how it relates to the half-life of the plain toothpicks

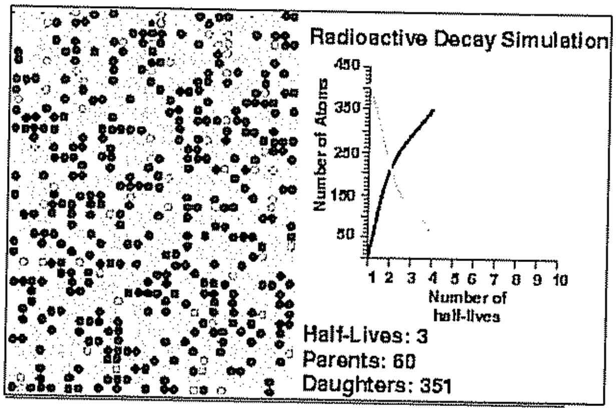

Fig 5 Right: frame from radioactive decay 'web-movie' that simulates parent atoms (gray dots) decaying into daughters (black dots) Neutral atoms (light gray dots) are also shown Left: decay curve is generated by plotting number of parents and daughters per unit time

5. Course evaluations and future work

Although this effort is just in its third year, we have some initial feedback about how well it is working It makes the class much more fun to teach (and TA) Anecdotally, we hear it makes the class more fun to take Some positive student comments are, "(The demos) gave a better picture of the concepts being explained", "(It was) rather interesting and innovative, such as 'Simulating radioactive decay' and 'Virtual

Earthquake'," "Most of the web-based stuff, like the virtual field trips, were interesting to read", "Simulated seismograph readings were some of the best uses of the website" and "The 'Virtual Earthquake' simulation was as helpful for understanding the concepts as using an actual seismograph". Some negative comments are, "(The web-resources were) a bit tedious, especially with the homework problems that had us summarize the material from a particular webpage" and "Often topics covered in webpages strayed too far off-tangent from the stuff covered in class"

In general, students like web-based exercises in place of standard homework problems (e.g. virtual earthquake and field-trips) and disliked summary, web-based reading exercises. Some of the best uses of the web are quantitative problems that use real data (e.g. planetary fact sheet, virtual earthquake and plate motion calculator) Moreover, it is important the course webpage be maintained by checking and updating links. Lost links are common, distracting and annoying!

With the further development of this class, we hope to determine a good mix of in class demonstrations and those via the World-Wide Web In addition, we would like to more fully gauge the impact of web-based activities It is not clear how to best encourage students to explore the concepts using the web. Asking students to simply regurgitate information from websites to show that they visited them is tedious for the instructor as well as the student, and does little to motivate learning Mostly, we use the Internet as a backup to class discussions and we are unsure whether or not it can be used as a primary learning tool. Whether it helps students learn more is difficult to assess but, we believe that it can be effective, based on results from relevant experiments (Renner, 1979; Ward and Herron, 1980; Hake, 1992) In addition, with the recent development of a 'science literacy test' (see DeLaughter et al., 1998) we will attempt to use students' preconceptions of geological phenomena to derive more adequate demonstration material In summary, we believe that a 'high'/'low' mix of demonstrations and simulations can better help students to visualize and understand geophysical concepts.

Acknowledgements

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