IBI* SERIES WINNER

An Inquiry-Based Curriculum for Nonmajors

Light, Sight, and Rainbows, the IBI prize-winning module, provides questions for exploring simple atmospheric phenomena.

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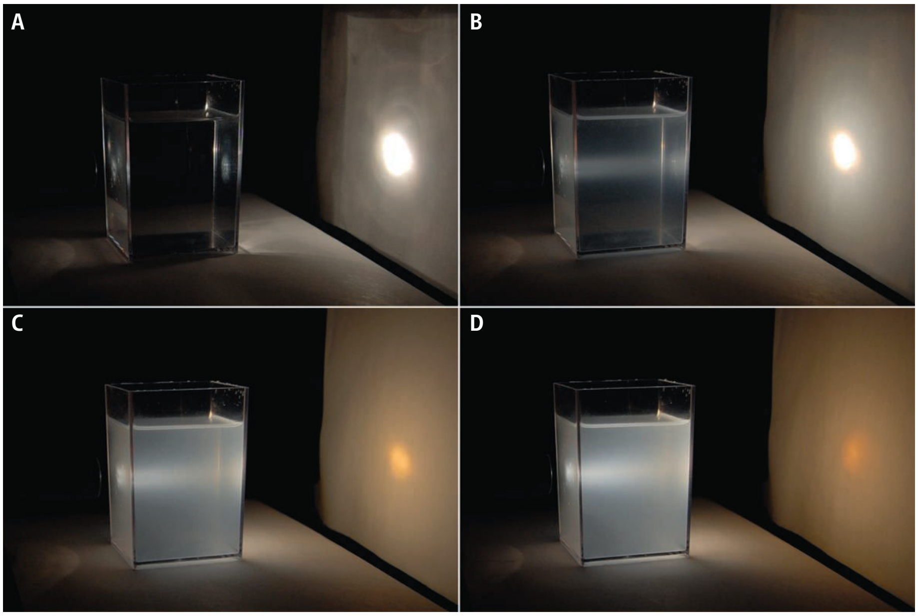
Only 28% of the U.S. adult population is considered scientifically literate. Although this is the second highest among 35 developed countries, a fact attributed to postsecondary science requirements (*1*), it should not be considered satisfactory, and improvement is critical to our future. A trend of many U.S. colleges and universities is to offer courses for nonmajors that cover a wide range of material via lectures, with few opportunities for students to engage in hands-on learning. This is particularly disturbing given that "a growing body of science educators has found that students' attitudes toward science, their motivation for learning, and their conceptual development … can all be enhanced by engagement in real scientific investigations" (*2*).

Explorations in Physics (EiP) is an inquiry-based curriculum designed to increase the scientific literacy of those who are not science majors and to impart a fundamental understanding of the nature of scientific investigation (*3*). The curriculum consists of a series of stand-alone units that use guided-inquiry instruction and culminate with student-directed projects (see the table). Each unit has undergone extensive testing and revision at Dickinson College, Santa Clara University, and Rochester Institute of Technology. More information is available on the EiP Web site, http://physics.dickinson.edu/EiP (*4*).

A defining feature of EiP is the emphasis on student-directed projects. After working through the "core material" on one or two topics, students embark on projects of their own design. Each group of three or four students is required to submit a proposal, design and conduct experiments, take and analyze data, draw conclusions, present their results in class, and submit a final written report. This requires a significant investment in student and instructor time. Hence, during the project phase, 100% of in-class time is spent working on these projects. Just as actual scientists do, students come face to face with ambiguity and the task of formulating concrete understanding in the face of measurement errors and other uncertainties. The repeatability of their measurements and whether or not these results can be convincingly extrapolated are what give students a true sense of how science progresses. It is precisely this type of understanding that we believe is necessary for citizens to be able to make informed judgments on the scientific issues they will face in the future.



Light through a simulated atmosphere. A flashlight beam through a container of water with varying amounts of milk. (**A**) No milk, (**B**) two drops, (**C**) six drops, and (**D**) eight drops.

Explorations in Physics Units
Published units
A. Force, Motion, and Scientific Theories
B. Light, Sight, and Rainbows
C. Heat, Temperature, and Cloud Formation
D. Buoyancy, Pressure, and Flight
Unpublished units available on the EiP Web site
E. Atoms, Crystals, and Snowflakes
F. Sound, Vibrations, and Music
G. Population, Climate, and Mathematical Modeling
H. Magnets, Charge, and Electric Motors

One of our favorite units is Light, Sight, and Rainbows (*5*). As is typical of all our units, this unit is designed to help students address phenomena that physics education researchers have determined to be difficult to understand. Our own research and that of others, most prominently the Physics Education Group at the University of Washington (*6*), has revealed that students have tremendous difficulty with the concept of sight and the necessity of light impinging on the eye in order to see. Our unit begins with the simple question, "Can you see in the dark?" This never fails to produce a rich discussion of what it means to see and the difference between self-luminescent and reflecting objects. Some students assert that sight will return once their eyes become dark-adapted. Others accept that they cannot see in the dark, but attribute to light a passive catalyst role to illuminate the object and allow our "sight" to become active. True to the experimental nature of the curriculum, once students have considered and discussed

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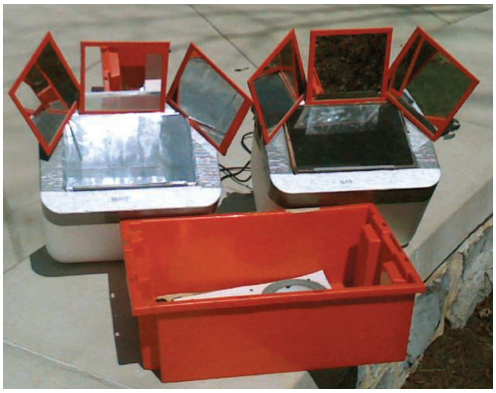
this question with each other, we plunge them into a "completely" darkened room (*7*). As students continue to argue, comment, and adapt to the dark, they gradually begin to distinguish fire-alarm LEDs and slivers of light around the edges of covered windows, but they still can't see an object sitting in the middle of the room. It finally dawns on them—in the absence of light, there is no sight!

Thus begins a journey in which students investigate how light travels, bounces, and bends and how images are formed with pinholes, lenses, and the human eye. The unit concludes with a study of color and dispersion that enables students to understand blue skies, orange sunsets, and the details of rainbow formation.

Topics in Light, Sight, and Rainbows often reappear with increasing complexity. For example, early in the unit, students shine a flashlight through clear water and note that although they cannot see the beam of light in the water, they do see a bright spot on a viewing screen placed beyond the tank. Adding a few drops of milk or a small amount of powdered creamer to the water makes the beam visible, but at the expense of the spot's brightness (and color, as the spot turns orange). Later in the unit, we return to this experiment to measure the relative amount of red and blue light transmitted through the water. Applying the concepts of reflection, scattering, and spectral composition, students use the results of this experiment to explain why the sky is blue and sunsets are orange (see the first figure). Subsequent student projects involving light include investigations of polarizing sunglasses, lenses, colored light on colored objects, and the "temperature" of color.



Solar ovens constructed by students. The black one reaches a higher temperature. Both were capable of baking cookies.

CREDITS: (LEFT) HANS PFISTER; (RIGHT, TOP AND MIDDLE) VIRGINIA L. JACKSON; (RIGHT, BOTTOM) SUE WEISLER/RIT

Student projects often combine themes from two units. For example, after completing guided inquiry on the light and heat units, one group of students constructed low-cost solar ovens out of Styrofoam packing crates (see the second figure). One was lined with flat black construction paper and another with reflective craft paper. The question was whether or not thermal absorption would be more effective than reflectivity. The students used mirrors to direct sunlight into the ovens and monitored interior and exterior temperatures with computer-interfaced sensors while baking cookies. To their surprise, the cookies really did bake! Their measurements revealed that the chamber with the black interior maintained a higher internal temperature, resulting in a shorter baking time for the cookies. The beauty of such an experiment is not so much the final result. It is that students gain a thorough and concrete understanding of a scientific topic by designing and carrying out an independent investigation.

Since the development of EiP began, many activities from our units have been described in publications (*8*–*12*). One important lesson we learned early in our development is that students need sufficient time to realize the benefits of the inquiry-based activities. It is all too easy to rush through activities and not give students the time necessary to make careful observations and to interpret their results. This is particularly important if students are expected to conduct meaningful self-directed projects. A typical unit requires between 18 and 24 hours of class time, with a similar amount of in-class time spent on projects.

Explorations in Physics has fulfilled our goal of increasing the scientific literacy of those who are not science majors in a way that encourages self-directed exploration. We hope the future brings this opportunity to students everywhere, helping them use investigative skills in their future endeavors and serve as scientifically literate citizens who contribute to the creation of a better world.

About the authors

David P. Jackson is Associate Professor of Physics at Dickinson College where he studies pattern formation in magnetic fluids and develops inquiry-based activities for physics majors and nonmajors. He has co-organized two Gordon Research Conferences on Physics Research and Education and is currently editor of the *American Journal of Physics*.

Priscilla Laws is research professor of Physics at Dickinson College where she has been developing activity-based curricular materials informed by the outcomes of Physics Education Research for introductory physics students. She has authored the *Workshop Physics Activity Guide* series and coauthored the *RealTime Physics Active Learning Laboratory Modules*, and *Physics with Video Analysis*.

Scott Franklin is professor of Physics at Rochester Institute of Technology where he conducts research in soft matter or granular materials and physics education. He was cofounding editor of the *Physics Education Research Conference Proceedings* and is currently secretary-treasurer of the American Physical Society Forum on Education and a founding member of Rochester Institute of Technology's Science and Mathematics Education Research Collaborative.

References and Notes

1. J. Miller, paper presented at the annual meeting of the American Association for the Advancement of Science, San Francisco, CA, 16 February 2007.
2. R. L. DeHaan, *J. Sci. Educ. Technol.* **14**, 253 (2005).
3. Explorations in Physics was developed with funding from the Charles A. Dana Foundation, the National Science Foundation (NSF), and the U.S. Department of Education's Fund for the Improvement of Post-Secondary Education (FIPSE).
4. D. P. Jackson, P. W. Laws, S. V. Franklin, *Explorations in Physics: An Activity-Based Approach to Understanding the World* (Wiley, New York, 2003).
5. This unit is available as supporting online material on *Science* Online.
6. For more information on the Physics Education Group at the University of Washington, visit their Web site www.phys.washington.edu/groups/peg/.
7. It is extremely difficult to completely darken a room. Fortunately, although the room needs to be quite dark, the room does not need to be 100% light tight for this demonstration to have an impact on students.
8. D. P. Jackson, P. W. Laws, in *The Changing Role of Physics Departments in Modern Universities* (American Institute of Physics, Woodbury, NY, 1997), pp. 623–630.
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