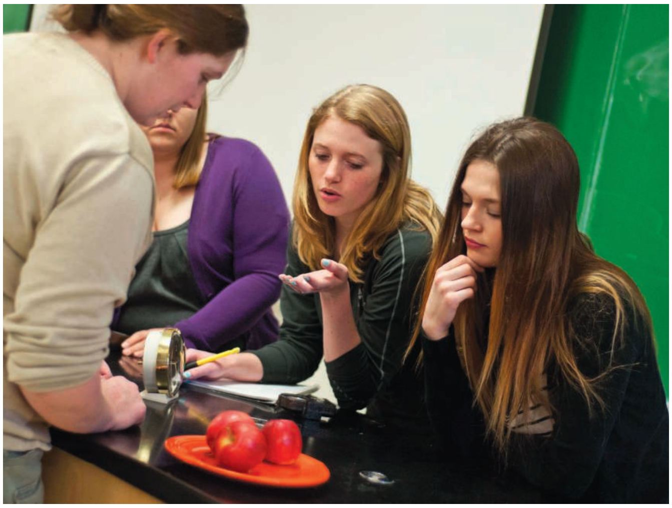
IBI* SERIES WINNER

Radiation and Atomic Literacy for Nonscientists

Inquiry into Radioactivity, an IBI prize–winning module, enables students to develop meaningful understandings of ionizing radiation through guided experimentation.

Andy Johnson

The student teams stand outside of their closed classroom door holding Geiger counters. Behind the door, the classroom has been salted with radioactive antiques, rocks, and commercially available sources. Their mission: safely locate the radioactive objects and quantify their radiation levels. Keenly aware that, thus far, they have only encountered background radiation, the team members wait expectantly, some uneasily, for this new task. Some of the team members are smiling, anticipating an experience something like a postapocalyptic Easter egg hunt. What will they find behind the door?



Students discuss whether apples on a radioactive antique plate will become radioactive.

A scene such as this is just another day in a classroom using the Inquiry into Radioactivity (IiR) course materials. The topics of radioactivity and ionizing radiation tend to be taught briefly, if at all, in science courses for nonmajors. However, ionizing radiation is becoming increasingly important in modern life. Gamma scintigraphy and x-ray computed tomography scans are increasingly used in medicine, industrial uses of radiation are proliferating, and the meltdown of the nuclear reactor at Fukushima has raised the visibility of radioactive hazards.

A society that uses nuclear technology needs to be radiation-literate. The IiR Project of the Center for Math and Science Education at Black Hills State University is developing tools and techniques to raise the level of radiation literacy among college and high school students who typically avoid science.

Most people do not know what radiation is. We, like other researchers, have found that students and the general public do not correctly understand ionizing radiation as high-speed particles emitted from radioactive atomic nuclei (*1*). Instead, most view radioactivity as its own sort of matter and typically do not distinguish between radiation and radioactive material. They think of both as something that spreads out from a source and affects other objects in the vicinity (*2*). Radiation is seen as "bad stuff," like dirt or germs, that "contaminates things." This general set of ideas prevails in the United States and Europe among all levels of introductory physics students (*3*), which makes it unlikely that students can reason meaningfully about radiation.

However, students can understand radioactivity without an extensive background in science. In order to make sense of ionizing radiation, students need to know what ionizing radiation is, where it comes from, and how it can do harm. Those three categories have guided the development of the IiR materials. And, although a number of IiR activities, including the radioactive object hunt, are fun for students, the goal of developing a functional understanding of ionizing radiation drives everything that happens in the classroom.

The IiR Project began in 2004 with the question "How much can students figure out about radiation by doing inquiry?" After years of development and classroom testing, our answer is, "quite a bit!" The teacher just has to present the students with the right experiences, questions, and classroom structure. The guided inquiry approach is used because students develop deeper understanding of science through interactive engagement methods such as inquiry (*4*, *5*). Moreover, it encourages students to learn more than scientific content—students develop scientific reasoning abilities as a natural consequence of learning science (*6*), and, a selfish motivation, the interaction of students in the classroom is much more engaging and enjoyable for everyone involved, including the teacher (*7*).

By exploring the classroom with cheap electromagnetic field detectors, each made from a guitar amplifier and a coil, students in the IiR classroom discover that electrical devices emit a different type of radiation that is not emitted from radioactive sources. By experimenting with an infrared remote control, a light sensor, and microphones, students determine that there are many different types of radiation, but only one type is detected by Geiger counters. Students test contamination by ionizing radiation directly by taping test objects—such as coins, pencils, or food—to classroom radioactive sources and checking their radiation counts after a weekend has passed (see the first figure). Many are very surprised (and a little disappointed!) that their test objects never become radioactive. By checking the penetration of radiation through different objects, students discover three types of ionizing radiation—alpha, beta, and gamma—and they are surprised to find that count rate and penetrating power are not connected.

Part of the challenge in developing a particle view of radioactivity is the need to understand that atoms emit radiation particles but are also damaged by radiation via ionization. We found that our students initially understand very little about atoms, despite previous education on the topic (*8*). Thus, the IiR materials explicitly focus on the structure and

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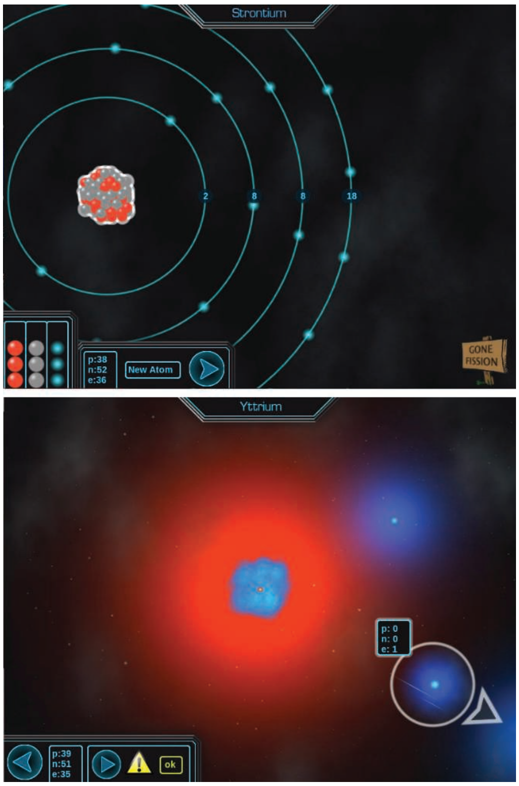
properties of atoms and on the interaction of ionizing radiation with matter. This required the development of new tools that enable students to do experiments on single atoms. The project designed special pedagogical simulators that reveal the invisible behavior of atoms. These simulators give results the same way macroscopic experiments would—phenomena are displayed in detail but no explanations are provided. Strategically designed questions in the course materials support students developing scientific ideas about atoms.

We developed a special Atom Builder simulation that allows students to "build" every known isotope from hydrogen to dubnium (element 105) (see the second figure). Students build atoms and then send them to a test world in which ions attract and repel each other, and unstable isotopes explode, releasing various particles. Students are drawn to Atom Builder by its gamelike look and feel. They want to play with it, and in doing so, they learn about atoms. Using the Atom Builder simulator in conjunction with the IiR materials, students develop useful, meaningful understandings of atoms, ions, and nuclear stability (*8*). Atom Builder and the other IiR simulators are available at www.camse.org/sims.

Later, when studying the interaction of radiation with matter, students use two other IiR simulators: (i) Atom Invaders, which allows students to shoot alphas, betas, gammas, and neutrons at individual atoms and molecules, and (ii) Tracks, which simulates the interaction of alpha, beta, and gamma radiation with everyday objects at three different size scales. Students use these to work out how radiation interacts with matter. The class gradually invents an explanation that radiation particles cause damage at the molecular scale by removing electrons from many molecules, often breaking molecular bonds. Developing this mechanism for the fundamental process of radiation damage enables the unit to continue with lessons on how radiation can damage DNA and cells. Additional IiR activities provide information on acute and stochastic radiation doses and medical uses of radiation.



The Atom Builder simulator. In the lower frame, strontium-90 has transformed to yttrium-90, emitted a beta, and self-ionized.

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Using IiR we find that the majority of students do not transition to the moving-particle view of radiation until they investigate emission and ionization at the atomic scale (*9*). By studying the ways that students spoke and wrote about radiation and the effects of exposure throughout a semester, we discovered that many students only abandoned their ideas of "radiation as stuff" and "contamination by radiation" after they completed investigations that revealed that the particle view can explain both the origin of radiation in nuclei and ionization effects.

Our findings suggest that a brief study of radiation and radioactivity (over a few weeks) will not lead students to shift their thinking about what radiation is. Regardless of the clarity or quality of the presentation, students will likely persist in thinking of radiation as having material-like properties that cause contamination. To come to understand what radiation is, most students apparently have to think long and hard about where radiation comes from and how it does harm. The IiR materials accomplish this by involving students in actively developing mechanistic models of radiation, atoms, radioactive decay, and ionization. Although this requires a substantial amount of class time, the effort results in radiation-literate students who carry with them deeper understandings of the world at the atomic scale.

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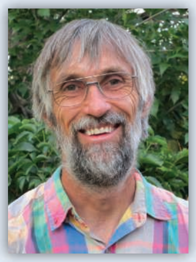
About the author



Andy Johnson is associate director for Science Education at the South Dakota Center for Math and Science Education at Black Hills State University and a physics education researcher trained in inquiry physics teaching and classroom research techniques. In addition to creating inquiry-based course materials, he teaches physics to college students and provides professional development to kindergarten through high-school teachers. Johnson received a B.S. in Physics at Colorado School of Mines, an M.S. in Physics at Arizona State University, and a Ph.D. in Physics Education at San Diego State University and the University of California at San Diego. Some of his students gripe about finishing each class exhausted from thinking hard, but many have also declared that the first time they ever understood science was in Johnson's class.

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