

# The Story of Science

## CLASSROOM COMPANION

EINSTEIN ADDS A NEW DIMENSION

TEACHER EDITION

JULIANA TEXLEY

**NSTA**press

National Science Teachers Association

Arlington, Virginia

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# RESOURCES FOR INTEGRATION AND IMPLEMENTATION

## TEACHER EDITION

In 1996, the *National Science Education Standards* (NSES) made a bold and impassioned plea for scientific literacy, or “the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity” (NRC 1996, p. 22). Moving away from the idea that science is for the elite, the authors of NSES defined the content, skills, and attitudes that were necessary for every citizen. Under this umbrella they included language arts skills, which were almost exclusively associated with the idea of “literacy” before the Standards expanded its definition.

In the years since the publication of NSES, the inclusion of language arts literacy skills into science and across the curriculum has been heavily emphasized. There has also been an effort to assess student achievement in informational reading, often using selections from textbooks as prompts. While research reaffirms the value of reading about science, quality science literature remains a rare find. Despite the best efforts of teachers, reading about modern physics has seldom been fun or motivating—not until the publication of Joy Hakim’s series *The Story of Science*.

*Einstein Adds a New Dimension*, Hakim’s third volume, is unique in both its content and its value as an outstanding science trade book. Enjoyable reading about modern physics may seem like an oxymoron—until you open to the first page. Reviewers have called Hakim’s prose some of the most exciting and accurate in the field. This great expository writing can become the foundation of an integrated program that infuses the knowledge, skills, and attitudes of scientific literacy across the curriculum.

With inspiration from the real scientists in the story, as well as their creative biographer Hakim, you can show your students the future. Please consider the ideas that follow simply as clues that can help you expand the potential of *Einstein Adds a New Dimension* in your school program.

## Using *Einstein Adds a New Dimension* in the Classroom

The *Story of Science* series is first and foremost good literature—trade books that are designed to spark the curiosity of students. Both the biographies of scientists and the descriptions of their experiments are meant to light fires in young minds. So the first recommendation for the use of *Einstein Adds a New Dimension* is read and enjoy!

The books represent fascinating informational reading. The format and text elements lend themselves to the teaching of informational reading skills in 7th- through 12th-grade language arts courses. However, the content of *The Story of Science* is, of course, science—that is, not just a body of facts but a process and way of knowing. So the reading must be inextricably linked to exploration and inquiry. Whether the books are used as the skeleton of a program or as support, they must be accompanied by hands-on exploration.

There are also mathematics and social studies links everywhere in these books, with tempting invitations to follow them to new adventures. Those unique features have made *The Story of Science* volumes very popular with schools that have developed integrated multisubject blocks, as well as with homeschool communities, where the boundaries between subjects are not as sharply defined as in traditional school programs.

The level of content and the minimal mathematics that are woven into *Einstein Adds a New Dimension* connect most easily to an integrated physical science program in grades 7 through 10, but the content in modern physics is every bit as rich as that found in most textbooks written for students in grades 11 through 13.

Both the Teacher and Student editions of this guide correspond chapter by chapter to *Einstein Adds a New Dimension* and offer<sup>1</sup>

- classroom demonstrations and activities that *engage* students in inquiry-based science lessons;
- original quotes<sup>2</sup> from well-known scientists that help students *explore* concepts in greater depth by connecting big scientific ideas to scientists' individual experiences;
- lists of important science terms that also can be used to *explore* concepts in greater depth;
- links to web resources that encourage active learning and help *explain* content;
- links to informational sites, where students can pursue independent research and *elaborate* on their understandings; and
- writing prompts through which to *evaluate* students' understanding.

In addition, the Teacher Edition also provides

- short synopses of each chapter;
- teaching tips for clarifying misconceptions and encouraging further inquiry;
- answers to the activity questions; and
- resources for further reading to expand background knowledge (or, perhaps, to recommend to precocious students).

The guide for teachers provides selected examples of the type of innovative ideas and activities from which professionals might develop a program that meets the needs of their particular students. Activities were selected for ease of implementation and are limited to those that involve a minimum of expensive equipment. In addition, wherever possible, mathematics, geography, and history notes are included so that the text can easily be integrated into subject areas other than science. Many of the activities are interchangeable since this story of science moves back and forth through time, space, and the physical universe. How education professionals add these “new dimensions” to their school’s curriculum will ultimately depend on the unique characteristics of their learning communities.

<sup>1</sup> In these components, we have referenced the “5 E” model for an inquiry-based lesson developed in 2006 by the Biological Sciences Curriculum Study. See the report “The BSCS 5E Instructional Model: Origins, Effectiveness, and Applications.”

<sup>2</sup> Many of the translations of these passages have been taken from Stephen Hawking’s collection *On the Shoulders of Giants* (2003).

## National Science Education Standards

*Einstein Adds a New Dimension* provides a great path to language arts literacy in the context of science. It's important to recognize that this cluster of skills is only one component of science literacy. The text also interweaves content from a variety of areas defined by the NSES. While many teachers will use this book successfully as part of a middle school program, most will find the book and the program built around it to contribute to achievement of these 9th- through 12th-grade standards:

Area	Standard
A. Science as Inquiry (p. 143)	Abilities necessary to do scientific inquiry Understandings about scientific inquiry
B. Physical Science (p. 176)	Structure of atoms Structure and properties of matter Motions and forces Conservation of energy and increase in disorder Interactions of energy and matter
D. Earth and Space Science (p. 187)	Energy in the Earth system Origin and evolution of the universe
E. Science and Technology (p. 190)	Abilities of technological design Understandings about science and technology
F. Science in Personal and Social Perspectives (p. 193)	Science and technology in local, national, and global challenges
G. History and Nature of Science (p. 200)	Science as a human endeavor Nature of scientific knowledge Historical perspectives

# A NOTE FROM JOY HAKIM

## TEACHER EDITION

The teacher was young, intense, and very bright. I had just given a talk, and she stayed to continue the conversation, telling me about a science lesson she had taught a few months earlier. She had led her students from experimentation, to discussion, to written analysis and, at the time, thought it was the best teaching she had ever done. So six weeks later, when her students were given a standardized test, she knew they would all get the correct answer to the question that dealt with the material she had taught on that inspired day. As it happened, not one student got it right. And when she spoke to some of them about the material, they hardly remembered her wonderful lesson.

She was baffled and asked if I had an explanation for her. She wondered, How do we make science stick? How do we take those terrific hands-on activities and help students turn them into concepts that they will hold in their minds?

The quick answer is not easily. Finding ways to help form retentive, thinking minds is a central educational challenge, especially today when knowledge, and the ability to find and use it, is key to success in almost every field of endeavor. Science, perhaps more than any other subject, seems to offer unique opportunities for mental stretching, and yet it's a subject that misses much of the school population. Why isn't contemporary science permeating curricula? Why are so many of our school graduates "scientifically illiterate"? How can adults with prestigious diplomas in languages, literature, or law consider themselves educated if they are without a basic understanding of modern physics or chemistry? Does it matter? Is broad scientific literacy really important?

Yes. We live in what is probably the greatest scientific era ever. The 20th century was a golden age for physics; we're in the midst of a golden age of cosmology; biophysics is coming on fast. Anyone without basic knowledge of those sciences is missing the intellectual underpinnings of our time. And yet that describes much of our population.

But aren't today's sciences very difficult? Aren't they only understandable to an intellectual elite? No question, the mathematical specifics of quantum theory and relativity (the two great physical science concepts of the modern era) are beyond many of us. But the overarching ideas are not.

Do these sciences impact our everyday world? You bet. We wouldn't have TV, computers, or cell phones if we hadn't delved into the quantum world. We wouldn't have GPS or space travel without general relativity. As to cosmology, it now takes us back—with stunning specifics—almost to the moment of creation. Recently we learned, with measured precision, the direction the universe is heading. The search for alien life, once the domain of science fiction, is now mainstream. School science is boring? Maybe we've been leaving out the good stuff.

In *Einstein Adds a New Dimension* you'll struggle with some astonishing concepts. Much of modern science is counterintuitive. It doesn't seem to make sense. That makes it challenging, and also—to use an appropriate cliché—mind-blowing. Science is a critical-thinking subject. It's an analytical-reading

subject. It's a stretch-your-mind subject, and we've been missing its potential. There are political implications: Leadership in science translates into world leadership. Science is now too important to be left just to scientists.

So what do we do? We consider science as a reading and thinking subject—without eliminating the traditional experiment-based approach. How can we possibly add anything else to the curriculum? We don't. We do some rethinking of the literary arts (and maybe social studies, too). Today's dominant literary form is narrative nonfiction. And some of the most creative nonfiction is coming from science writers. We're proposing that you consider science as both a reading subject and a doing subject.

Then science becomes a several-bangs-for-your-buck endeavor. Link activities to a narrative and you will teach subject matter as you hone reading and thinking skills. There's an important bonus: Educational psychologists tell us that students are likely to remember facts woven into a story. Our experience tells us that reading comprehension scores go up with vocabulary-rich narrative nonfiction. It's the classic approach to teaching.

From Homer to McGuffey's readers, stories are the way that cultures have traditionally passed on their most important ideas. In recent times, we've gotten away from storytelling. The very word *story* has been given a negative connotation—"Don't tell me a story, tell me the truth." But the best stories are true. And we all know that truth is stranger than fiction.

Why did Dutch police set out after Daniel Fahrenheit when he wanted to build a thermometer? What happened when Niels Bohr tried to climb up a bank building in Copenhagen? What famous American physicist was a prankster skilled at cracking safes? Science is boring? No way. *Einstein Adds a New Dimension* takes the scientific adventure into the 21st century (it began in ancient Greece in *Aristotle Leads the Way* and journeyed into the world of classical physics with *Newton at the Center*).

Schools talk a lot about multidisciplinary learning, and The Story of Science books are intended to help make it possible. Ideally, science, language arts, history, and math teachers will use the books in a joint exploration. However, if no team is available and you're on your own with the books, just put on multiple hats. Science is an arena in which everyone can become an explorer.

You don't feel secure with the material covered? So much the better. You won't be tempted to lecture. Create an environment in which you and your students learn together. Let them become the experts. They'll love taking that role. These books were written with the hope that you and your students would question, research, discuss, and write—thus honing essential information-age skills.

Science is an unending search for answers; the best scientists are those who learn to pose challenging questions. This teachers guide and accompanying student pages will ease you and your students into the process. We expect you to embark together on an adventure for your minds. Hardly anything is as intellectually satisfying as today's science.

# 24 THE FISSION VISION

TEACHER EDITION

*Leo Szilard was the contrarian, constantly posing questions that seemed unanswerable. Enrico Fermi was the hard worker, spending endless hours resolving his students' questions. As Adolf Hitler built support for his Nazi agenda, these scientists built on the work of Frédéric and Irène Joliot-Curie, Lise Meitner (who was also fighting gender bias in the scientific world), and others. Ultimately, the physicists found a self-sustaining process of nuclear fission that would change the world.*

## Teaching Tips

Although they may have heard the term many times, students often have difficulty conceptualizing the process of nuclear fission. The kinesthetic simulation below, as well as the two suggested applets, are worthwhile activities for clarifying the process of nuclear fission. Ask students to respond to what they model and observe in discussions and journal entries.

Another point of confusion is the source of fission energy—the nucleus rather than the electron shells. Remind students that before fission became a reality, even physicists were skeptical that bombarding a nucleus with neutrons could create significant energy. Labeled drawings can help clarify this concept.

## Fission Simulation

Students can model nuclear fission in an open space. In the following simulation, students represent uranium atoms, either U-235 (which is fissile) or U-238 (which is nonfissile), while the teacher represents the neutron. Students draw roles at random, based on predetermined ratios. For the first simulation, 25% of students should draw fissile. Once roles have been assigned, students stand in a matrix formation, leaving 1 m between one another. (Discuss this arrangement with students as they move to their positions: The rigid structure may remind them of atoms in a crystal.)

Make sure students understand the directions for their roles. The neutron (teacher) walks into the formation in a straight line and touches the first atom (student) he or she encounters. If the atom is nonfissile, nothing happens. The neutron continues on the same straight path and touches another atom at random. When a fissile atom is touched, that student silently counts, “One tomato, two tomato, three tomato,” then shouts, “Bang,” and quickly (but gently) tags all the other students within arm’s reach. If one of the atoms touched is nonfissile, it remains still, but if it is fissile, it repeats the count and then tags surrounding atoms. Capture and play back the simulation via audio or video recorder. The class can count the number of “bangs” that occur until the process stops.

In the second round, students draw new roles. This time designate 50% of them fissile; in the third round designate 75% fissile. Students should track the number of generations of reactions (“bangs”) for each percentage of fissile atoms using the chart on page 60:

% Fissionable	# of Generations of Reactions
25	
50	
75	

While discussing the data, students can compare the various ratios they have modeled and answer the following questions (answers in **bold**):

1. What percentage of fissile atoms produced the longest/strongest chain reaction?  
**75%**
2. Why? **The chain reaction is longer because the likelihood of finding a fissile atom is higher.**

You may also want to extend the discussion to incorporate current events. News stories often cite the role of governments in enriching uranium. Lead your class into a discussion of the high ratio of fissile to nonfissile isotopes necessary for the chain reaction to be perpetuated.

3. On the news you often hear the term *enriched uranium*. Why do scientists enrich uranium before fission can occur? **The higher the percentage of fissionable material, the stronger the reaction.**

Encourage students to look carefully at the diagram on page 217 of *Einstein Adds a New Dimension*. Note that when the first neutron hits the uranium-235, two neutrons are released in addition to the original one. In the next reaction, potentially nine neutrons are released. Have students complete the table showing the reaction number and number of free neutrons (see p. 61) and answer the following questions:

4. How many reactions are required to release at least 1 million free neutrons? **13**
5. Graph the number of free neutrons in each reaction. What is the shape? **The result is a curve in the shape of a J.**
6. If each reaction takes about  $10^{-7}$  second, how long will this process take?  **$13 \times 10^{-7}$  seconds**
7. In fission reactors, rods are sometimes used to slow reactions. If a rod absorbed one of every three released neutrons, how would the shape of the graph change? **It would slope later but have the same J shape.**

Reaction	# Free Neutrons
1	3
2	
3	
4	
5	
6	
7	
•	
•	
•	
▼	
n	> 1 million

### Vocabulary

- Fission
- Fusion

### Online Learning Tools

Chain Reaction: Mouse Trap Model

[www.physics.umd.edu/lecDEM/services/demos/demosp4/p4-62.htm](http://www.physics.umd.edu/lecDEM/services/demos/demosp4/p4-62.htm)

Nuclear Fission

[www.lon-capa.org/~mmp/applist/chain/chain.htm](http://www.lon-capa.org/~mmp/applist/chain/chain.htm)

### For Further Investigation

Einstein's Big Idea: Messing With Mass

[www.pbs.org/wgbh/nova/teachers/activities/3213\\_einstein\\_03.html](http://www.pbs.org/wgbh/nova/teachers/activities/3213_einstein_03.html)

Nuclear Science in Society: Student Fission Activity

[http://old-www.ansto.gov.au/edu/pdf/stu\\_act1\\_9.pdf](http://old-www.ansto.gov.au/edu/pdf/stu_act1_9.pdf)

### Extended Reading

Sullivan, E. 2007. *The ultimate weapon*. New York: Holiday House.

### Evaluation

The student page includes the following scenario as a tool for assessing students' understanding of nuclear fission:

Physicists love to do rough, “back of the napkin” estimates. These are often called Fermi Questions after Enrico Fermi. Here’s a Fermi Question for you: Look at the chart below. It shows the energy needed to get from Earth to the dwarf planet Pluto, at the edge of our solar system, if we were to harness the energy of a fission reaction. Compare that to the energy available in gasoline. If we could somehow create a gasoline-powered rocket, how much fuel would we need to get to Pluto? How much mass would that represent?

Answers are in **bold**.

Fuel	Mass (g) per Molecule or Reaction	Energy Released per Molecule/ Reaction (eV)	# of Reactants/ Reactions Needed to Get to Pluto	Total Mass of Fuel Needed
Fission	$4 \times 10^{-23}$	$2 \times 10^7$	$3.5 \times 10^{24}$	680
Gasoline	$1.9 \times 10^{-22}$	66	<b><math>1.2 \times 10^{31}</math></b>	<b><math>2.3 \times 10^9</math></b>

Source: Adapted from NOVA, “A Trip to Pluto.” [www.pbs.org/wgbh/nova/teachers/activities/3213\\_einstein\\_05.html](http://www.pbs.org/wgbh/nova/teachers/activities/3213_einstein_05.html), where complete answers, explanations, and extensions can be found.

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# 24 THE FISSION VISION

## STUDENT EDITION

### Fission Simulation

With the help of your teacher, you can model nuclear fission with your class. Each student will represent a uranium atom, either U-235 (which is fissile) or U-238 (which is nonfissile). Your teacher will mimic the neutron.

First, take a card from your teacher, but don't tell the other students what role you've drawn. Then, in a wide-open space arrange yourselves in a matrix; make sure you stand about 1 m from one another. As you take your places, consider how the "structure" you're creating compares to a crystal.

Once everyone is ready, your teacher initiates the reaction by walking into the formation in a straight line and touching a student at random. If you are touched and you're a nonfissile atom, remain totally still. If you are touched and you're a fissile atom, silently count, "One tomato, two tomato, three tomato," then shout, "Bang," and quickly (but gently) tag all the other students within arm's reach. With the help of an audio or video recorder, log the number of generations of bangs that occur until the process stops.

Complete this process three times, and each time draw a new role. At the end of the three rounds, summarize your data in this chart:

% Fissionable	# of Generations of Reactions
25	
50	
75	

1. What percentage of fissile atoms produced the longest/strongest chain reaction?

---

2. Why?

---

3. On the news you often hear the term *enriched uranium*. Why do scientists enrich uranium before fission can occur?

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Next, grab a calculator and look carefully at the diagram on page 217 of *Einstein Adds a New Dimension*. It represents a chain reaction. Note that when the first neutron hits the uranium-235, two neutrons are released *in addition to* the original one. In the next reaction, potentially nine neutrons are released. Complete the table showing the reaction number and number of free neutrons:

Reaction	# Free Neutrons
1	3
2	
3	
4	
5	
6	
7	
•	
•	
•	
▼	
n	> 1 million

4. How many reactions are required to release at least 1 million free neutrons?

---

5. Graph the number of free neutrons in each reaction. What is the shape?

---

6. If each reaction takes about  $10^{-7}$  second, how long will this process take?

---

7. In fission reactors, rods are sometimes used to slow reactions. If a rod absorbed one of every three released neutrons, how would the shape of the graph change?

---

## Vocabulary

- Fission
- Fusion

## Online Learning Tools

Chain Reaction: Mouse Trap Model

[www.physics.umd.edu/lecDEM/services/demos/demosp4/p462.htm](http://www.physics.umd.edu/lecDEM/services/demos/demosp4/p462.htm)

Nuclear Fission

[www.lon-capa.org/~mmp/applist/chain/chain.htm](http://www.lon-capa.org/~mmp/applist/chain/chain.htm)

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## Evaluation

Physicists love to do rough, “back of the napkin” estimates. These are often called Fermi Questions after Enrico Fermi. Here’s a Fermi Question for you: Look at the chart below. It shows the energy needed to get from Earth to the dwarf planet Pluto, at the edge of our solar system, if we were to harness the energy of a fission reaction. Compare that to the energy available in gasoline. If we could somehow create a gasoline-powered rocket, how much fuel would we need to get to Pluto? How much mass would that represent?

Fuel	Mass (g) per Molecule or Reaction	Energy Released per Molecule/ Reaction (eV)	# of Reactants/ Reactions Needed to Get to Pluto	Total Mass of Fuel Needed
Fission	$4 \times 10^{-23}$	$2 \times 10^7$	$3.5 \times 10^{24}$	680
Gasoline	$1.9 \times 10^{-22}$	66		

Source: Adapted from NOVA, “A Trip to Pluto.” [www.pbs.org/wgbh/nova/teachers/activities/3213\\_einstein\\_05.html](http://www.pbs.org/wgbh/nova/teachers/activities/3213_einstein_05.html), where complete answers, explanations, and extensions can be found.