

Thanks for using *Suspended in Language* in your classroom. The following are some ideas for generating discussion, critical thinking, and further learning based on what your students just read.

Content questions

Which character—besides Niels Bohr—do you find most memorable? Why? Be as specific as you can.

Describe the difference between classical physics and quantum physics.

What was the world like when Niels Bohr was born? What was it like when he died? [Do you think you'll see changes that are that big?]

Albert Einstein and Niels Bohr argued most of their lives, but remained close friends. Why do you think that is?

Werner Heisenberg is a controversial figure to many scientists. Why?

Do you agree with Bohr when he says that the military use of science is inevitable? Justifiable?

Why does quantum physics matter? Do you think it ever affects you in your daily life? [Trick question: Not directly, but computers wouldn't work without it, for one thing!]

What chapter or story do you find most effective? Why? Be as specific as you can.

How would you describe Leland Purvis' artistic style? What is its most striking feature? How do you compare it to Roger Langridge's style?

Choose a page in the book and describe how the writer and artist combine words and pictures in effective ways.

Take a look at pages 11 and 102. Why do you think they're so similar? How about pages 204-208?

What point do you think is being made on pages 253-259?

Which characters do you find to be the most interesting and engaging? That may be different than most memorable! Why? [Which character would you like to go on a vacation with? Which character(s) would you want to invite over for dinner?]

How would you describe the tone of the book? Cite specific pages and/or panels as examples.

Before reading this book, what was your attitude about Niels Bohr? Werner Heisenberg? About the issue of scientists being involved in politics? In what ways has the book changed your mind about these issues and peoples?

What artists do you think influenced Leland Purvis? Jay Hosler? Linda Medley?

If you could ask the artist(s) any questions, what would they be?

If you could ask the writer any questions, what would they be?

Storytelling questions

Why do you think pages 298-300 were done that way? How does it change the way you hear the story?

Why do you think Leland uses a different style on page 132, panel 1, and positions the characters in an unusual way?

On page 150, what happened between panel 1 and panel 2? What happened between page 91 and page 92?

Pay close attention to backgrounds throughout these stories. How do the writer and artist establish and treat setting and environment?

Why did the story start with Bohr speaking directly to you? Why does the story end with him doing the same thing?

Why do you think the art looks the way it does in "Apocrypha" (The barometer story?)

Ask the characters! Ask yourself!

Now that you've read the book, try answering some questions as if you were one of the characters. Then, pretend like you were in the character's situation. How would you answer it for yourself?

"Professor Bohr, what do you think of the internet?"

"Professor Einstein, do you still think quantum mechanics is an incomplete theory?"

"Professor Bohr, why did you leave Denmark during the war?"

"Professor Heisenberg, why did you stay in Germany during the war?"

Vocabulary

photon
proton
neutron
electron
quantum
wave
fission
complementarity

More to explore

Books

Niels Bohr: A Centenary Volume edited by A.P French and P.J. Kennedy (Cambridge, MA: Harvard University Press, 1985).

I'll admit it: I initially bought this for the pictures. But beyond the photos, this book is full of anecdotes, sidebars, and science. No single volume I've seen gives a better overview of Bohr's life and work, so if you've enjoyed *Suspended in Language* please seek this out as well.

The Atomic Scientists: A Biographical History by Henry A. Boorse, Lloyd Motz, and Jefferson Hane Weaver (New York: Wiley Science Editions, 1989).

From Lucretius to C.N. Yang & T.D. Lee, thousands of years of physics history and personalities come to life in this essential reference.

The Character of Physical Law by Richard Feynman (Cambridge, MA: The M.I.T. Press, 1965).

An excellent introduction to the nature of modern physics, Feynman's discussion of the double-slit experiment is the clearest I've read.

In Search of Schrödinger's Cat: Quantum Physics and Reality by John Gribbin (New York: Bantam Books, 1984).

You can tell by the broken spine and smudged pages of my copy that this is still one of the best introductions to the unlikely ideas of quantum physics I've read. (No assembly, batteries, or math required!) Recommended without reservation.

Copenhagen by Michael Frayn (New York: Anchor Books, 1998).

See this play if you ever have the opportunity. (There's also a PBS adaptation of it for television, available on DVD). Though it takes dramatic liberties, it is, after all, a drama, and a terrific one. The interest it sparked in the Bohr-Heisenberg wartime meeting contributed to the Niels Bohr Archive releasing Bohr's unfinished letters years earlier than they had intended.

Niels Bohr's Times in Physics, Philosophy, and Polity by Abraham Pais (Oxford: Clarendon Press, 1991).

The most comprehensive book about Bohr I know of. Pais was a first-rate physicist as well as a friend and confidant of both Einstein and Bohr. His insights into their personalities and science are singular...as is the structure of the book, (What was he thinking?) Anyway, if you can get past the odd narrative, between this and French and Kennedy's volume you'll get a complete and compelling picture of Niels Bohr as scientist and *mensch*.

Thirty Years that Shook Physics: The Story of Quantum Theory by George Gamow (Garden City, NY: Doubleday & Company, 1966).

A great source of anecdotes about all the superstar physicists of the early 20th century. Gamow was one of them too, but lives on mostly via his cartoons and humorous writing—he was a frequent contributor to the *Journal of Jocular Physics*, and the illustrator of “Copenhagen Faust.”

Atoms in the Family by Laura Fermi (Chicago: University of Chicago Press, 1954).

Very personal and a whole lot of fun—the spouses of genius don't always get their say.

Articles

“Did Bohr Share Nuclear Secrets?” by Hans A. Bethe, Kurt Gottfried, and Roald Z. Sagdeev, *Scientific American*, vol. 272, no. 5, May 1995, 84-90; “The Scientist and the Statesmen: Niels Bohr's Political Crusade during World War II” by Finn Aaserud, *Historical Studies in the Physical and Biological Sciences*, vol. 30, no. 1, 1999, 1-47; and “What Did Heisenberg Tell Bohr about the Bomb?” by Jeremy Bernstein, *Scientific American*, vol. 272, no. 5, May 1995, 92-97.

These are great pieces on the wartime intrigues Bohr found himself involved in.

“Quantum Teleportation” by Anton Zeilinger, *Scientific American*, vol. 282, no. 4, April 2000, 50-59 and “Trillions Entwined” by Graham P. Collins, *Scientific American*, vol. 285, no. 6, December 2001, 26.

A more thorough accounting of teleportation, entanglement, qubits and other spookiness. The first article even has a one-page comic strip—the mark of quality in any writing about science.

The following lectures/papers were presented at the “Copenhagen Symposium” held in Washington DC on March 2, 2002, sponsored by The Graduate Center of the City University of New York: “Notes on Comparing the Documents of Heisenberg and Bohr Concerning their Encounter in 1941” by Gerald Holton; “Frayn's ‘Heisenberg’: Fact or Fiction” by Jochen H. Heisenberg; “The Drawing or Why History is Not Mathematics” by Jeremy Bernstein; “‘A Great and Deep Difficulty’: Niels Bohr and the Atomic Bomb” by Richard Rhodes; “The Bohr-Heisenberg Meeting from a Distance” by Finn Aaserud; “On the Copenhagen Interpretation of Quantum Mechanics” by John Marburger.

All are available at <http://web.gc.cuny.edu/ashp/nml/artsci/symposium.html> and provide accounts of Bohr and Heisenberg's meeting, their troubled relationship with each other, and the history they made. Jochen Heisenberg's memories of his father are particularly affecting.

"Heisenberg, Uncertainty and the Quantum Revolution" by David C. Cassidy, *Scientific American*, vol. 266, no. 5, May 1992, 106-112.

"Bringing Schrödinger's Cat to Life" by Philip Yam, *Scientific American*, vol. 266, no. 6, June 1997, 124-129.

Sites

Visit the terrific "Visual Quantum Mechanics" at <http://phys.educ.ksu.edu/> to see electron waves in action!

For something in a more classical mode, you can see a tippe-top simulation at <http://www.physik.uni-augsburg.de/~wobsta/tippetop/>, but you really should try and get a hold of one yourself. And you can (while supplies last) by visiting <http://www.gt-labs.com/>.