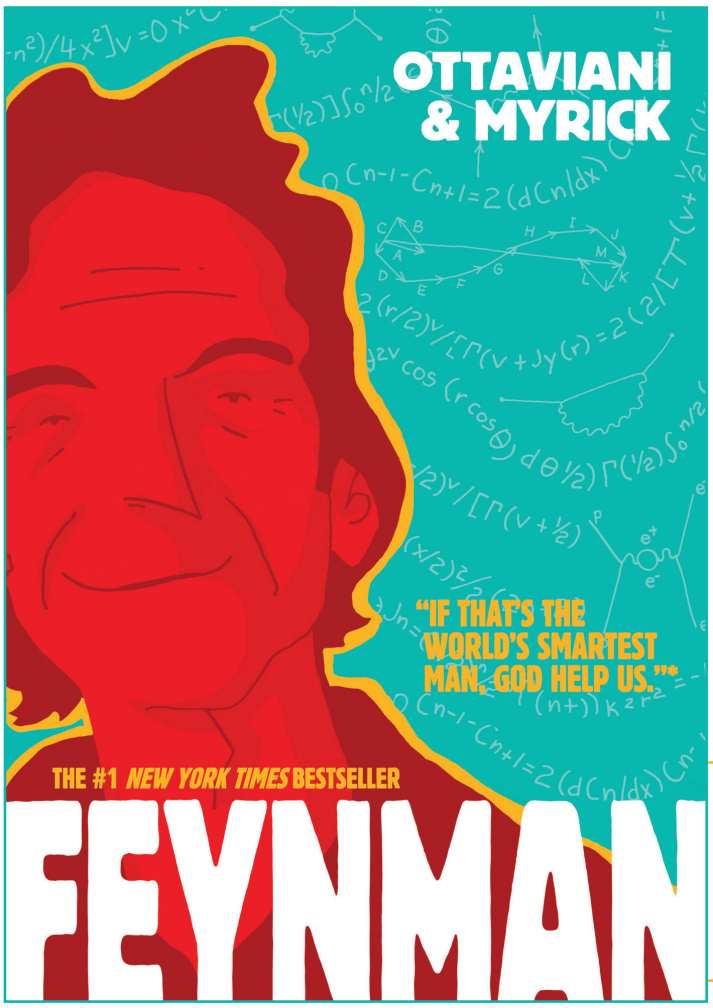
TEACHER'S GUIDE

FEYNMAN

WRITTEN BY JIM OTTAVIANI
ILLUSTRATED BY LELAND MYRICK



ABOUT THE BOOK:

Feynman is a biography of physicist and author (and artist and teacher and musician and . . .) Richard P. Feynman. Told in graphic novel format, it begins during Feynman's grade school years and follows his life, discoveries, and adventures through to his death in 1988. Jim Ottaviani and Leland Myrick created this biography using a rich pool of documentation: Feynman's own autobiographical work, historical accounts, anecdotes from friends and family, and the Feynman papers in the California Institute of Technology archives.

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ABOUT RICHARD FEYNMAN:

Richard P. Feynman was one of the most interesting physicists of his, or any, generation, with passions ranging from quantum electrodynamics to bongo drums to the obscure nation of Tuva. He was a key member of the team that developed the atomic bomb and part of the commission that investigated the Space Shuttle Challenger disaster. In addition, he has been credited with pioneering work in the fields of quantum computing and nanotechnology. Feynman was passionate about not only science itself, but science education as well; he often said that if something could not be understood by a freshman level science class, no one really understood it. He put his money where his mouth was, and became the only Nobel prize winning physicist to construct a course in basic college physics. The resulting textbooks, titled *The Feynman Lectures on Physics*, have remained popular and in print since they were first published in 1963.

He often cracked wise, and sometimes cracked safes.

OBJECTIVES:

This guide will provide teachers with the background knowledge necessary to effectively use *Feynman* in the classroom when discussing math, physics, and their applicability to 20th century US history. It includes questions and commentary on both the content of *Feynman* and the graphic novel format.

BOOK-SPECIFIC QUESTIONS:

1. pages 5-6: Feynman, and his dad before him, have little patience with merely knowing the names of things. But can you give examples of why it's helpful to at least know them? Are there examples later in the story where it would have helped Feynman himself to use language that others can understand?
2. page 11: This story is called Nobel Speech #2. What's different about it from Nobel Speech #1 (on page 173-175) and why did Feynman choose non-technical topics for both?
3. page 20: Do you think Feynman had the neurological condition called synesthesia, or simply an active imagination? Is having a condition like this a prerequisite for being a genius? (After all, he talks about this experience in class as his only feeling of being ordinary.)
4. page 31: What was happening in Europe in the 1930s?
5. page 44: Dirac closes his famous book saying "It seems some essentially new physical ideas are here needed." Are there textbooks that ought to end with that line, or something similar, today?
6. pages 47-49: Feynman has a few interactions with Einstein, and they turn out well. What does Feynman learn from them?
7. page 60: Feynman talks about this (visual) equation later, on pages 180-181. Did he make the right decision here, given what he knew at the time? What would you have done?
8. page 79-85 : Feynman's first public safecracking exploit turns on luck, and this is one of the most famous stories about him and where his reputation officially blossoms, per the Oak Ridge memo. How do you think this affected his later life, and the legends that built up around him? Do you think he actively sought out situations that would add to his reputation, or did they just fall into his lap?
9. page 89: Do you agree with Feynman's self-assessment in the first panel?
10. pages 95-97: How does Feynman's reaction to Arline's death, from the moment it occurs through to his letter, line up with what we know about him as a person? As a scientist?
11. page 107: Why does Feynman have trouble returning to civilization? Do you think he wanted to return? Are there parallels to others whose lives were (and still are) interrupted by war?

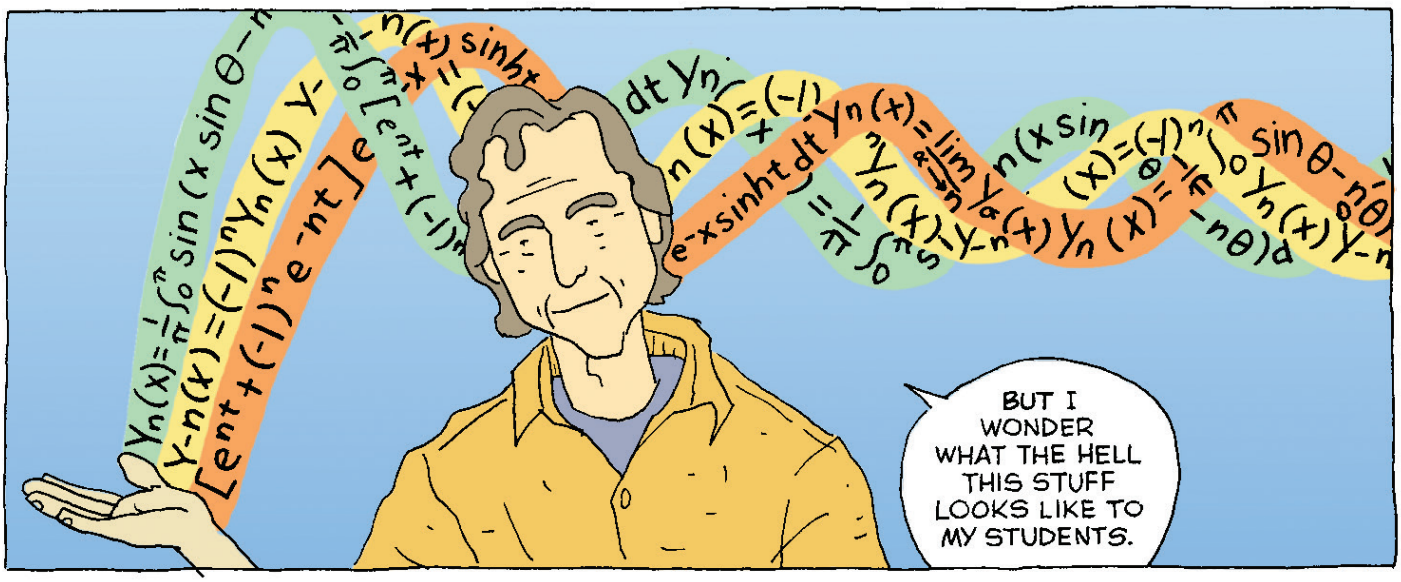
12. pages 113-114: Can you think of other cases in science where a sense of playfulness led to important discoveries?
13. pages 129-131: Why did Feynman have so much trouble writing his seminal paper?
14. page 133-135: Feynman also made a similar decision later regarding the dessert menus at restaurants; at a certain point he vowed to never weigh his options again because the answer would always be chocolate ice-cream. What do you think was behind these decisions?
15. page 163-166: If you're read or listened to Feynman's Lectures, do you think he's right to be "not dissatisfied"?
16. page 177: Is Feynman right about what people can and can't talk about?
17. pages 200-201: So, Feynman doesn't understand QED—he just follows rules! Sure, he discovered and created some of those rules, but still . . . . If you believe him (do you?) is this admission consistent with his character and previous behavior?
18. page 229-231: We've seen Feynman fool around with DNA, nanotechnology, and on these pages supercomputers, not to mention art and music. What was lost by his spending time on these other pursuits? ("Nothing" is a possible answer, of course!)

QUESTIONS FOR DISCUSSION:

1. What section or scene do you find most effective? Why? Be as specific as you can.
2. How would you describe Leland Myrick's artistic style? What is its most striking feature?
3. How would you describe the tone of the book? Cite specific pages and/or panels as examples.
4. Before reading this book, what was your attitude about physicists? In what ways has the book changed your mind about them?
5. Does Feynman fit the model of the type of person you think about when you think "scientist"? Why or why not? Consider some of the classically famous scientists—Newton, Galileo, daVinci—when you think about this question.
6. During the 20th century, how did peoples' conceptions of what science is and what it's used for change? What role did Feynman play in this change?
7. How do you think people think differently about science now than they did when Feynman was growing up? Is the world a very different place?
8. If you could ask the artist one question, what would it be? If you could ask the writer one question, what would it be?

STORYTELLING QUESTIONS:

1. The scenes are presented in only rough chronological order, with a good deal of skipping around. Are there places where this worked particularly well (or poorly)?
2. Choose a page in the book and describe how the writer and artists combine words and pictures in effective ways.
3. On pages 150-153, we see Feynman's trouble with women after Arline's death reach a peak, and then come to a more-or-less abrupt end a year later. What clues do you have that this is coming, and how is it reflected upon later in the story?
4. (Skip this one if you're a professional physicist!) QED is explained in some detail on pages 197-210 and 218-226. Compare this to the explanation of the theta-tau puzzle on page 150. Did you understand the details (or even the broad strokes) in that earlier scene? Why do you think they're handled differently?
5. page 206: With the reversed word balloons, we're all of a sudden explicitly seeing this comic book as a comic book. Why here?
6. Along these same lines, as the story nears its end it moves back and forth from Feynman's mortality to explaining QED. Given that the writer and artist could have had him talk about physics any time throughout the book, what dramatic purpose do you think it serves to put these scenes where they are?
7. Take another look at the backgrounds throughout the story. How do the writer and artist establish and treat setting and environment?
8. How does color affect the storytelling? Can you decide why it isn't used realistically in some places?



GLOSSARY:

action: in physics, a way of talking about a particle in terms of the units energy x time to describe the path or trajectory it takes through space; in general, these paths are such that the action is minimized (see the principle of least action below)

amplitude: the maximum absolute value ("height," when shown on an x-y axis) of some quantity that varies; used to describe waves

cosmic rays: particles originating in outer space that pass through Earth's atmosphere; mostly protons

cyclotron: a device that accelerates charged particles, such as protons or electrons, to high velocities via high-frequency, alternating voltages and magnetic fields

diffraction: the process by which light (or other waves of subatomic particles) spreads when past through an aperture or slit; interference patterns typically result

electron: the negatively charged particles that surround ("orbit") the nucleus of an atom; when zooming off on their own they're also know as beta rays

fission: splitting; in the atomic sense, when a nucleus breaks into two pieces, releasing neutrons and energy in the process

inertia: sorry, Feynman wouldn't want us to define this one, would he?

magnetosphere: the field around a planet like Earth that forms when charged particles, such as from the solar wind or cosmic rays, interact with our planet's magnetic field.

möbius strip: a one-sided loop, made by putting a half-twist in a strip of material before joining the ends

neutron: one of two particles that make up an atomic nucleus; a nuclear chain reaction occurs when neutrons released during fission strike neighboring nuclei, causing them to fission as well

path integral: a formulation of quantum physics that—in contrast to the notion that a particle takes a single, unique trajectory through space—sums up an infinite number of possible paths for a particle to arrive at an outcome.

photon: a particle of light . . . or is it a wave?

principle of least action: a principle used to get equations of motion for particles in a system; in classical (as opposed to quantum) mechanics there is a similar principle in stating that light travels between two points along the path of shortest time between them

proton: a component of the atomic nucleus and cosmic rays as well; similar in mass to a neutron, but with a positive charge

quantum electrodynamics: the theory of how light and matter interact

quantum mechanics: the theory of particles and waves that provides a description of their behavior, such as wave-particle duality, at atomic and subatomic scale

self-action/self-energy: the effect of a particle's own action or energy upon itself

solar wind: the stream of particles, mainly electrons and protons, ejected from the upper atmosphere of the sun

spin: in quantum mechanics, a measure of a particle's intrinsic angular momentum; thinking of an electron as spinning like a top, though, isn't helpful, since its spin is ½!

synesthesia: the condition where stimulation of one sense leads to an experience in a second sense; involuntarily ascribing colors to taste, sounds, or even thoughts are synesthetic acts

uncertainty principal: in quantum mechanics, a theory that describes the inability to know two complementary properties of an object with infinite precision

uranium: a naturally occurring element used in nuclear fission

wave-particle duality: the idea, central to quantum mechanics, that particles can show wave-like characteristics, depending on what an experimenter is measuring; for example, in the early 20th century electrons were observed to diffract as if they were waves when passed through a pair of slits.

BIBLIOGRAPHY

A complete bibliography for the book is available at the G.T. Labs website: www.gt-labs.com/feynman.html.

ABOUT THE CREATORS

Portrait by Leland Myrick

Jim Ottaviani's many books on science and scientists have been nominated for multiple awards, including Eisners and ALA Popular Paperback of the Year. They've received critical praise in publications ranging from *The Comics Journal* to *Physics World* to *Entertainment Weekly* to *Discover Magazine*. Jim had hoped to work with artist **Leland Myrick** ever since nominating him for an Ignatz Award in 1999 for his book *Sweet*. Since then Leland has earned many addition award nominations for his books *School Girls*, *Bright Elegy*, and *Missouri Boy*. His work has appeared in publications all over the world.

Self-portrait by Leland Myrick

A BRIEF INTERVIEW WITH JIM OTTAVIANI

In a sense, Feynman covers well-trod ground, since there are already many books by and about him. Why another one?

There are indeed a lot of books about him. But even after all this time and all those books, there are still people out there who have never heard of this fascinating and influential physicist. And some of those people might never read something about science, at least in prose form, even if they have heard of him. So we think a biography done in comics, in full color, will reach some of those holdouts.

Which, I suppose begs the question, "Why care about those holdouts?" My answer to that is simple: I think Feynman is important, and not just as a scientist. Not even as a scientist who was also a wise guy and myth-maker and storyteller; a son, brother, husband, father, teacher and friend. All of those things factored into a life lived in full color, and I hope point out that science and discovery is a profoundly human thing to do. It sometimes gets done by people on their own, in the dead of night with only a pencil, paper, and a glimpse into how the universe works. But it's also done in the company of other people, and affects them, and is part of a complete life. I know I'm starting to sound like a cereal commercial ("Fortified with eight essential vitamins and minerals, and part of a balanced breakfast!") so I'll leave it to Feynman himself to make the point: "You cannot develop a personality with physics alone, the rest of your life must be worked in."

He worked it in.

Why comics?

Comics are a great medium for telling a lot of story in a small space, because in the hands of an expert artist—and Leland Myrick is that and more—you get information from both the words and the pictures.

Feynman's work in particular is perfect for comics, since he was always drawing. He doodled, he sketched, he exhibited his art in galleries. (Under a pseudonym, since he didn't want people to buy his work just because he was a famous physicist.) And while that was important to him, even more important was having his "funny-looking pictures," what we now know as Feynman diagrams, become the standard way of solving the deep and complicated puzzle of how light interacts with matter.

And as I said above, if ever there was ever anyone who lived his life in full color, it was Richard Feynman, so color is the way to go for this story. It made showing some of Feynman's physical insights possible in ways that black and white couldn't.

Color plays an important role, then?

It certainly does. Like I said, it wouldn't be possible (or at least efficient) to portray some of the physics in the book using only black and white. To say more would be to give some surprises away, so I'll stop there. But I can't stop talking about color without noting that color is more than just useful for explaining physics; it's a subtle and efficient way to set the mood of a scene. I've never had it at my disposal before, and *Feynman*'s colorist Hilary Sycamore impressed me over and over with her smart, creative color design. Leland had worked with her on Missouri Boy and he told me to trust her. That wasn't easy—I'm something of a control freak—but he was right. It turned out great!

With regards to the physics, is the work Feynman did still relevant? Science does move on, after all . . .

It does, but successful theories—think evolution via natural selection, special and general relativity—endure, and QED is successful. Meaning, as scientists do more and different experiments the theory continues to agree with the results they obtain. Sure, refinements get made, but the core of these theories hold and the ideas behind them remain influential. QED meets those criteria.

Well, QED was a group effort, though. Schwinger and Tomonaga contributed to it as well, for starters. Why do we still talk about Feynman?

True, and as we tried to show in the book, they arrived at it via different paths, and the whole became at least as great as the parts. But here's where we get specifically to Feynman: The techniques he pioneered are still in use today as well. A quick check: as I write this, the pair of articles in which Feynman introduced his diagrams have been cited over 400 times since 1988. That's a lot, and these are just the basic papers, nothing more . . . and his techniques have become so ubiquitous that most people don't bother to cite him at all, just as they don't cite Newton's *Principia* or Darwin's *On the Origin of Species*.

Most scientists would love to have that much influence while they were alive, much less after they died.

Okay, but that's the scientific community, and most of us don't work as theoretical physicists. What about the rest of us?

Right, though again, it's not just theoretical physicists who are influenced by QED or use Feynman Diagrams. But your point is well taken, in that what I've said doesn't get at the bigger picture. That's when I look to what Feynman did for physics education with his undergraduate *Lectures* and his ideas about nanotechnology and his work on parallel computing and his service on the Rogers Commission investigating the Challenger disaster and . . . the list goes on. He shared *what* he knew, and better than that he shared *how* he came to know things. He was interested in thinking and discovery.

And stories.

Yes! And stories most of all. Feynman sought out good stories, and he made sure he lived a good story as well. When his life started to lack plot or conflict, he put himself in a position to have some of both. I recently read a book by William Gurstelle called *Absinthe & Flamethrowers: Projects and Ruminations on the Art of Living Dangerously*, and in it he talks about risk taking. He mentions Dr. Marvin Zuckerman, who has created a testing instrument called the Sensation Seeking Scale, which he uses to quantify the test taker's propensity for risk. When you plot out a lot of peoples' responses, you get what scientists and mathematicians call a normal distribution. It's what most people think of as a "bell curve" and on both extremes are folks you don't want to have plan your next vacation—unless you want to sit around and watch reruns on TV or skydive without a parachute. Most of us live somewhere in the middle third.

Anyway, yes, I do have a point. Feynman lived his life in what Gurstelle calls "The Golden Third" of that curve. Not so risky as to be foolish, but well past the point where a life wouldn't be worth writing about. If we all found our way into that area, we'd all have books written about us—at least if we also made fundamental contributions to our understanding of the universe and did some other stuff on the side as well!