Understanding Einstein: The Special Theory of Relativity

A Stanford University Online Course
Larry Randles Lagerstrom, Instructor

"The important thing is not to stop questioning. Curiosity has its own reason for existing. One cannot help but be in awe when one contemplates the mystery of eternity, of life, of the marvelous structure of reality. It is enough if one tries to comprehend only a little of this mystery every day."
Albert Einstein

Course Description

In this course we will seek to "understand Einstein," especially focusing on the special theory of relativity that Albert Einstein, as a twenty-six year old patent clerk, introduced in his "miracle year" of 1905. Our goal will be to go behind the myth-making and beyond the popularized presentations of relativity in order to gain a deeper understanding of both Einstein the person and the concepts, predictions, and strange paradoxes of his theory. Some of the questions we will address include: How did Einstein come up with his ideas? What was the nature of his genius? What is the meaning of relativity? What's "special" about the special theory of relativity? Why did the theory initially seem to be dead on arrival? What does it mean to say that time is the "fourth dimension"? Can time actually run more slowly for one person than another, and the size of things change depending on their velocity? Is time travel possible, and if so, how? Why can't things travel faster than the speed of light? Is it possible to travel to the center of the galaxy and return in one lifetime? Is there any evidence that definitively confirms the theory, or is it mainly speculation? Why didn't Einstein win the Nobel Prize for the theory of relativity?

About the Instructor

Larry Lagerstrom is the Director of Academic Programs at the Center for Professional Development at Stanford University. His degrees include a Ph.D. in history and an M.A. in physics from the University of California at Berkeley. Before coming to Stanford he taught for sixteen years at U.C. Berkeley and U.C. Davis, covering subjects ranging from the history of science and technology to computer science and engineering. He has received three awards for excellence in teaching.

Prerequisites

This non-credit course is open to all. Knowledge of basic algebra will be helpful but is not required to complete the course. A math review is provided in one of the introductory video lectures.

Required Materials

There are no required textbooks or materials that students must purchase. The essential course content will be covered via video lectures and handouts.

Optional Reading

An optional reading on the life and work of the young Einstein is available online for US$2.99 (or the equivalent in foreign currencies) via Amazon direct publishing: L. Randles Lagerstrom, "Young Einstein: From the Doxerl Affair to the Miracle Year," https://www.amazon.com/Young-Einstein-Doxerl-Affair-Miracle-ebook/dp/B00BKKHS4U/

Required Commitment

The course is designed to allow students with differing levels of time and commitment to benefit from taking it, though a certain minimum level of commitment is of course necessary to gain the value desired. Though the course is self-paced, the material is structured so as to be covered over a recommended eight week period. Most weeks will have three to six hours of video lectures to watch (each lecture in the range of 5-30 minutes). Some of the lectures will also have pre-lecture "priming the brain" or "engaging the brain" questions to ponder for a few minutes before watching the video. (These are provided via handouts.) An ungraded practice quiz (usually three to eight multiple-choice questions) follows most video lectures, in order to help you learn the material and assess your understanding. At the end of each week there is a graded "final quiz," again consisting of multiple-choice questions pertaining to the week's material. All in all, therefore, the minimum level of commitment will be approximately five to ten hours per week for eight weeks. Students may also do an optional weekly problem set (starting in Week 2 and ungraded), which will require an additional one to three hours each week.

Weekly Schedule and Assignments

Note on "Three Approaches": In the original version of the course, which ran in 2013, students could choose one of three approaches to the course: a more quantitative approach, a more qualitative approach, or an auditing approach. Every once in awhile you will hear references to these three approaches in the video lectures. But the course has more recently been reformatted to be a self-paced course (though, as noted above, still designed to be done ideally over an eight-week period). You should therefore ignore the occasional references to the three approaches. The current self-paced version allows you either to audit the course or to take the course for a certificate (the latter requires payment, see the Coursera website for details).

Self-paced but Eight-Week Schedule: Although the course is self-paced, it is recommended to follow the eight-week schedule as outlined below and on the course website. In order to encourage this rhythm, and also to allow students to benefit from each other's questions and insights via the discussion forum as they work through the material on the same schedule, a new session of the course starts every four weeks. If you enroll early before the next official start date, you will have access to the Week 1 materials so that you can go ahead and get started. And, of course, if you want to move through the material faster or slower than the recommended schedule, that's fine. If you aren't able to make it through all the material in eight weeks, you can request a switch to the next session being offered (see the Coursera website for details).

What To Do Each Week (more details given below):
1. Watch the video lectures for each of the week's lessons, using the accompanying handouts (posted on the course website immediately before each lecture) to take notes.
2. Do the ungraded practice quiz after each video lecture (or series of lectures).
3. Review the week's lessons and quizzes and then take the final graded quiz.
4. Optional extra work (ungraded): Try the problems in the weekly problem set, ideally without looking at the posted solutions first.

Readings/Handouts and Video Lectures: Each week's material is divided into several lessons, with one or more video lectures per lesson. In most cases, each video lecture has a "reading" that goes along with it. This reading is a handout that gives a basic outline of the lecture (with space for you to take notes, which is highly recommended). The handout also sometimes has "priming the brain" exercises and/or additional information about the lecture topic. So before starting the video lecture you should take a look at the handout and, if you wish, print it for note-taking purposes. (You can find the handout posted immediately before each video lecture on the course website, labeled as a "Reading.")

Practice Quizzes: Most video lectures have an ungraded practice quiz that comes immediately after the lecture. (In a few cases the quiz covers several related video lectures.) The quiz typically has three to eight multiple-choice questions. The questions are based on the material presented in the video lecture and are usually not too difficult if you have paid attention (and especially if you have taken some notes).

Weekly Final Quizzes and Course Certificate: At the end of each week's lessons there is a final graded quiz on that week's material. Each final quiz has between eight and twelve multiple-choice questions. If you have enrolled in the course to earn a Course Certificate, then you must earn a score of at least 80% on each of the eight final quizzes (one for each week of the course). You are allowed to make three attempts at a quiz per every eight hours (though note that the questions may be different each time). To study for a given final quiz, it is recommended to review your notes, the practice quizzes for each lecture, and the weekly summary lecture.

Weekly Problem Sets (optional): For students who want an additional challenge, Weeks 2-8 have problem sets consisting of three to five questions each. These questions typically require further thinking about the week's material and some basic calculations. Solutions to each problem set are posted in a separate file in case you get stuck or want to check your answers.

Course Outline

Week 1: Introduction and Einstein in Context
Introduction
1. Why take this course?
2. Overview of the course
3. How to succeed in the course (or any course)
4. Rules of engagement
5. Math review

Einstein in Context
1. Week 1 introduction
2. Physics and Einstein *circa* 1900
3. To the miracle year
4. The miracle year
5. Week 1 final quiz

Week 2: Events, Clocks, and Reference Frames
1. Week 2 introduction
2. Events, clocks, and observers
3. Spacetime diagrams
4. Frames of reference
5. A few more words on world lines
6. The Galilean transformation
7. Week 2 summary and final quiz

Week 3: Ethereal Problems and Solutions
1. Week 3 introduction
2. Einstein's starting point: the two postulates
3. A few words about waves
4. The Michelson-Morley experiment
5. Stellar aberration
6. Ethereal solutions
7. Week 3 summary and final quiz

Week 4: The Weirdness Begins
1. Week 4 introduction
2. The relativity of simultaneity
3. The light clock, and exploring the Lorentz factor
4. Time dilation
5. Measuring length
6. What is not suspect, and the invariant interval
7. A real-life example: the muon
8. Week 4 summary and final quiz

Week 5: Spacetime Switching
1. Week 5 introduction
2. Units for the speed of light
3. Exploring time dilation and length contraction (part 1)
4. The Lorentz transformation
5. Exploring the Lorentz transformation
6. Leading clocks lag, revisited
7. Exploring time dilation and length contraction (part 2)
8. Combining velocities
9. The ultimate speed limit

10. What happens with perpendicular velocities?
11. Week 5 summary and final quiz

Week 6: Breaking the Spacetime Speed Limit?
1. Week 6 introduction
2. Spacetime diagrams revisited (parts 1-5)
3. Regions of spacetime
4. Faster than light?
5. Cause and effect, or vice versa?
6. Week 6 summary and final quiz

Week 7: Paradoxes to Ponder
1. Week 7 introduction
2. Cause and effect: spacetime diagram
3. The pole-in-the-barn paradox
4. How objects contract, and spaceships on a rope
5. The twin paradox
6. Week 7 summary and final quiz

Week 8: To the Center of the Galaxy and Back
1. Week 8 introduction
2. Traveling the galaxy (part 1)
3. The famous equation
4. Traveling the galaxy (part 2)
5. The happiest thought
6. The bending of light
7. Final comments
8. Week 8 summary, course recap, and final quiz