Teaching Special Relativity: Minkowski trumps Einstein

Richard Conn Henry
Henry A. Rowland Department of Physics and Astronomy
The Johns Hopkins University

Students find physics difficult—I am thinking of first-year undergraduate university physics majors. I found it difficult myself, and it took me almost 40 years of teaching physics to fully understand the reasons for the perceived "difficulty." *Why* do students who find mathematics *easy* to understand, find physics *difficult* to understand?

There are two parts to the answer. First, and most importantly, by "understand" students mean "fit into my existing correct understanding of what the world is." Since the students' existing understanding of what the world is, is, in fact, quite *incorrect*; and since what *is* correct is almost impossible for the average person to believe; there is a gigantic barrier to understanding physics. (The barrier is, however, entirely psychological.)

Secondly, the physics that they are being taught is not *correct* physics; it is engineering approximations only. So, not only does what they are being taught not make sense in terms of the students' (incorrect) worldview, it does not even make sense in terms of a correct quantum-mechanical worldview.

It is a wonder that anyone at all *ever* sticks to physics, and grasps it.

Correct physics is of course quantum mechanics. Quantum mechanics has effortlessly survived intense attacks by the most brilliant of physicists; quantum mechanics will at minimum be with us for my lifetime and yours; it is the basis of all of our current thinking, and it provides our current *conception* of the universe, encapsulated in the headline "Measurements Are the Only Reality, Say Quantum Tests" (Glanz 1995).

Non-relativistic quantum mechanics leads to Maxwell's equations, which are Lorentz invariant (Dyson 1990). After quantum mechanics itself, Minkowski's union of space and time into spacetime is the greatest advance that has ever occurred in our understanding of the nature of the universe (that is, of the observations).

How grotesquely badly we *teach* special relativity encapsulates the practical problem of teaching physics to the freshman physics major. I have never found a single freshman physics textbook that teaches Minkowski spacetime; I have never found a single text on General Relativity that mentions "Einstein's two postulates."

Every physics freshman is taught … well, let me quote an example. In the fall of 2007 I will, for the second time in my career, teach introductory physics for physical science majors at the Johns Hopkins University. One text that has recently been used for that course is "University Physics," by R. L. Reese. On page 1155 we read "The entire special theory stems from only two postulates …. **Postulate 1:** The speed of light in a vacuum has the same numerical value *c* when measured in any inertial reference frame, independent of the motion of the source and/or observer." … **Postulate 2:** The fundamental laws of physics must be the same in all inertial reference frames."

The reader is invited to recoil, not only at the bizarre re-numbering of the infamous two postulates, but of course at the use of the postulates at all.

There is no doubt that, historically, Albert Einstein, in 1905, *did* introduce *two* postulates (and also, that it is he who discovered special relativity). But the second of these postulates (the one concerning the constancy of *c*, just in case Reese has confused you!) did not survive the year. In September of 1905 Einstein published a development from relativity—the discovery of the implication that $E = mc^2$, and in this new paper he mentions a single postulate only. But the paper contains a sweet footnote: "The principle of the constancy of the velocity of light is of course contained in Maxwell's equations." How I love that "of course!" Einstein was human!

I do not know if it is true, but I recall being told that during the Middle Ages undergraduates learned to multiply and divide using Roman numerals, while the exotic Arabic numerals were reserved for the more advanced students.

That is exactly what we do today in teaching special relativity. Antique postulates that are not of anything but historical interest to genuine physicists are presented to students as "Special Relativity." Some books do better than others in warning students how seemingly impossible the second postulate is; but all have the students working out true but unintuitive consequences (e.g. relativity of simultaneity) using thought experiments with of course the second postulate producing the bizarre result.

A small number of texts (Ohanian, Knight, a few others) at least follow Einstein's second paper in having but a single postulate; but none do what needs to be done, which is to drop Einstein and adopt Minkowski.

I feel that the time has come to relegate the "two postulates" to the dustbin of history, and to teach special relativity to undergraduates (or indeed, to middle school students) the Minkowski way.

I believe it is around grade nine that students are taught the Pythagorean Theorem. It is taught as mathematics, and no hint is given that "the keys to the kingdom" are in hand. That happens, of course, because the teacher does *not know* special relativity.

All that is additionally required is the recognition that one can, if one wishes, measure distances using imaginary numbers. And, that the same is true for *time*! Students react well to the suggestion that time is the fourth dimension. And then I say, "I can visit Rome, but I cannot visit Julius Caesar. So we need some *distinction* between space and time. Suggestions, please?"

Almost always, after some Socratic prodding, I do get "use imaginary numbers for one, and real numbers for the other?" I reward the student by announcing "you have just discovered Einstein's theory of special relativity!"

The notion that the Minkowski metric describes spacetime is entirely plausible to the students. It is not counter-intuitive, in any way, at least on its face. I announce to the students that experiment is the test!

Once students agree that the Minkowski metric *might* describe the world, it is of course extremely easy to deduce that *if* this should be *our* world, then there must be a limiting velocity. Everything else then follows with ease, and the students emerge comfortable with special relativity as a marvelous insight into the mathematical structure of the observations—the observations that we naively interpret as a universe.

REFERENCES:

Glanz, J. 1995, Science 270, 1439
Dyson, F. J. 1990, Amer. J. Phys. 58, 209