Why and how to teach the Special Theory of Relativity in an *Electrodynamics* course

Jingbo Zhang
Department of Physics
Harbin Institute of Technology
Harbin 150001
People's Republic of China

Abstract

In this paper, a new module for the teaching of Special Theory of Relativity is developed within an electrodynamics course. Problem based learning and case study approaches will be used in the module.

Introduction

Classical electrodynamics is the physical theory of the electromagnetic field and the interaction between the field and charged particles. It was introduced by Maxwell in 1880s based on physical experiments. The Special Theory of Relativity was published by Einstein in 1905 and became well known to the public because of its strange results and its changed perspective on spacetime. Special Relativity is a theory about spacetime. In most opinions, electrodynamics and Special Relativity are two individual physics theories. So, why would we rather teach Special Relativity in an electrodynamics course? Historically, most electrodynamics textbooks include one or more chapters talking about Special Relativity, and most electrodynamics courses teach Special Relativity. There are some historical reasons for this. The most important reason is that the development of Special Relativity has a direct relationship with electrodynamics. However, recently some physics departments in western universities have cancelled the module of Special Relativity in electrodynamics courses. In China some academics would consider following the western approach and reform electrodynamics courses. I do not believe that it is the right reform for our course. I still insist on teaching Special Relativity in my electrodynamics course, for it is the best and most natural way to introduce Special Relativity to the students. On the other hand, I must redesign the module to suit the whole course. In this paper, I will give a module design for teaching Special Relativity in an electrodynamics course. Regarding new teaching approaches, I will give two examples that discuss the use of problem based learning (PBL) and case studies within the course.

Course design

As one of the major courses for students in the physics department, classical electrodynamics is a very important and systemic module. Generally, in most of the universities in China, the course is designed for third year students. These students have learned classical mechanics in first and second year, and have learned electromagnetic theory at a general level in first year.

In this paper, I discuss a teaching plan for the electrodynamics course for the third year students. They are given 72 hours of lectures in one semester with 5 hours per week. As shown in Table 1, the whole course is divided into seven chapters. The first four chapters focus on the electromagnetic field and Maxwell's equations. In this section, the electromagnetic potential and its equations, and the propagation and radiation of the electromagnetic wave are also introduced. These form the main body of the course. Special Relativity is given as an individual chapter. I think this is the most suitable way to introduce the theory. The last two chapters cover electrodynamics from a field theory viewpoint and the interaction between particles and fields. This part is based on Special Relativity.

Within this framework, the Special Theory of Relativity is introduced in chapter 5. In teaching Relativity, the sequencing and organisation of material are both important, because the theory itself has a very clear logical construction and historical development. This part is taught as four levels shown as the right column in Table 1. The first level is the experimental and theoretical background of

Table 1. Contents of an electrodynamics course including Special Relativity

Classical Electrodynamics	Special Theory of Relativity
Chapter 1 Electromagnetic Fields	**5.1** Background
Chapter 2 Electromagnetic Waves	**5.2** Postulates
Chapter 3 Electromagnetic Potentials	**5.3** Transforms
Chapter 4 Electromagnetic Radiations	**5.4** Spacetime
Chapter 5 Special Theory of Relativity	**5.5** Mathematics
Chapter 6 Covariant and Canonical Field Theory	**5.6** Kinematics
Chapter 7 Particles and Fields	**5.7** Mechanics
	5.8 Dynamics

Special Relativity. In this level, the central purpose is to answer the question 'Where did the theory of relativity come from?' Here, I will use a case study teaching approach which is talked about in the next section. At the next level, I teach the main contents and results of the theory, including Einstein's two postulates, Lorentz transformations and Einstein's view of spacetime. Here, I would rather to use the PBL approach. This level will answer the question 'What is relativity all about?' I will design a lecture to discuss the mathematics related to Special Relativity, i.e. 4-dimensional spacetime and Minkowski's space. The last task is to describe the covariant physics, including mechanics and electrodynamics.

Case studies

Case studies are specific, highly focused and well defined. Case studies are selected and specified by the lecturer, and end with asking specific questions which relate to the curriculum. Characteristically, they tend to use problems that are always realworld problems. They are inevitably cross-disciplinary to some degree and involve historical and social background. The solution should be relevant to the students, discipline, or the society in which we live (Liu, 2004).

In the teaching of Special Relativity, the most difficult thing for the teacher is that the students may not accept the theory and its spacetime. They may think that the theory is too strange. Indeed, the theory is strange and hard to understand. However, it is the truth. If the students learn it in some natural and logical way, they will find it acceptable. For this purpose, I will design case studies for my students at the beginning of the course. With the case study, students will find the answers to the questions 'Why do we need relativity?' and 'Where did relativity come from?'

The cases are organised by a series of historical materials about Special Relativity (Figure 1). The materials focus on the status of experimental and theoretical development before 1905. The selected line is based on two major questions: 'Which reference frame are Maxwell's Equations corrected in exactly?' and the other one is 'What is the media for the propagation of electromagnetic waves?'

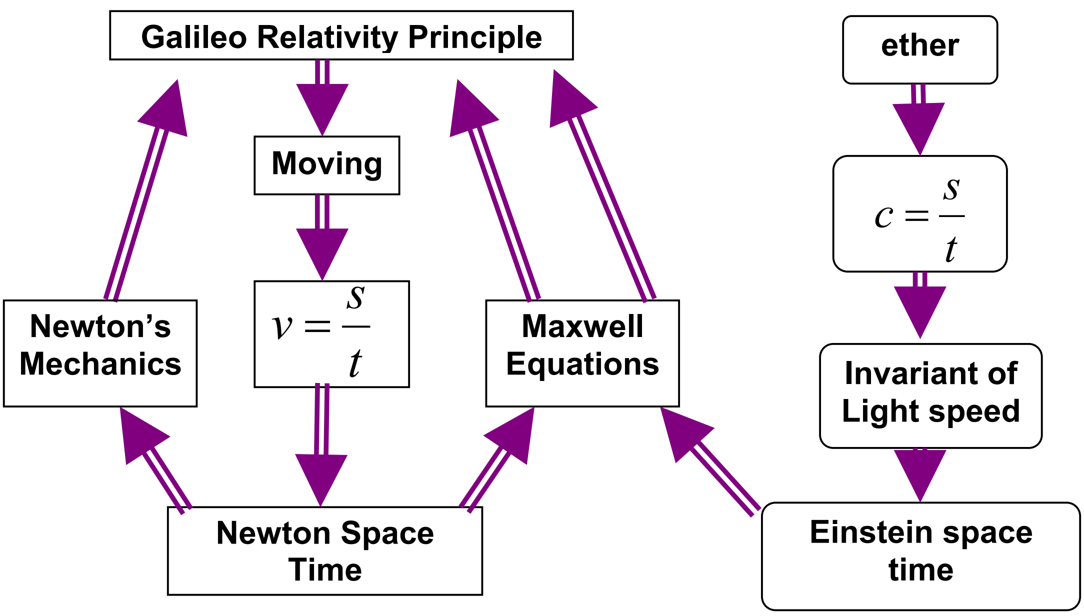

Figure 1. Concept mapping of Einstein's finding in 1905

Problem based learning

During recent decades, problem based learning (PBL) has become very common in the teaching of science in western countries. This is one of the most exciting and powerful new education tools, along with groupwork and research, case studies, guided design, and engineering design projects (Woods, 1994). PBL is a learning environment that embodies most of principles that we know are capable of improving learning. PBL is active, can be set up in such a way that requires cooperative effort, and provides prompt feedback. It can also be tailored to suit individual student needs (Peng, 2004).

Einstein himself realised that a consequence of his postulates was that our understanding of the nature of time needed to be revised. The set of events that is simultaneous to one observer is not simultaneous to another observer. As an example, Einstein provided us the following 'thought experiment' to show that 'Simultaneity is relative', the so-called 'Einstein's Train'. This is a very typical and suitable example problem for problem based learning in the course.

The problem can be described as following:
On a railway, there is a train moving at a certain speed (Figure 2). Lightning strikes the front and back ends of the train. The lightning strikes leave marks on the train and on the tracks. For an observer, John who stands on the ground halfway between the marks on the tracks, suppose Jack receives ('sees') the light emitted from the front and back of the train simultaneously, and concludes that: 'since I am midway between the marks on the tracks, and since the speed of light is a constant, then these two events are simultaneous'. The question is, for another observer, John who rides in the middle car of the train, what is his conclusion of these two events?

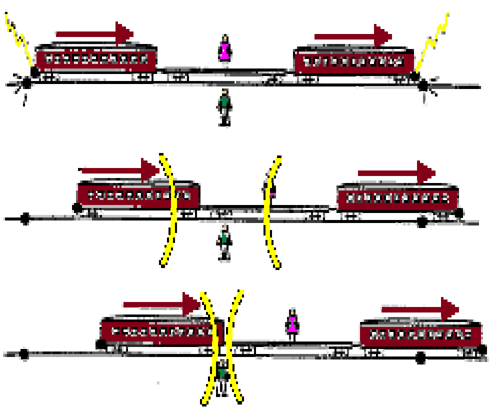

Figure 2. A trip on Einstein's Train

This is a typical problem in teaching Special Theory and also a confusing question for most beginners in Relativity. John receives ('sees') the light emitted from the front, then from the back, and concludes that: 'since I am midway between the marks on the train, and since the speed of light is a constant, then these two events are NOT simultaneous: the front one occurred before the back one'. Thus, each inertial observer will have a different sense of which events are simultaneous. On the other hand, if he still insists on the speed of light changing as Newton believed, he may conclude that these two events occurred simultaneously. So this is a very easy way to show the strange spacetime view of Relativity. As stated above, students can learn the background of the experiment by case studies. They know that the invariance of the speed of light is an experimental result and should be accepted as a fact. So the strange spacetime view should be also accepted logically as it is derived from the above. Because they calculate the result by themselves, they will accept the result and relativity more naturally. Generally, this problem is introduced in the first few lectures or is given at the end of lectures. However, in physics, this is very easy problem for college students. The concepts and knowledge related to this problem are simple and clear. The confusing point is just the explanation of the answer.

Conclusions

In conclusion, the best and most natural way to introduce Special Relativity is to teach it in an electrodynamics course. In a redesigned module of Special Relativity, some modern teaching approaches such as problem based learning and case studies are used.

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