Course planning task – UP2.1 Fall 2021, U. of Helsinki

Planning the course "Introduction to Relativity Theory"

Oscar Henriksson

Description and background information of the course

The course "Introduction to Relativity Theory" is given once a year in the Department of Physics and is recommended for the students of the Bachelor's program in Science in the Physics study track in their first years of studies. Similar courses in Finnish and Swedish are also given as parts of the Bachelor's program in Physics. The focus of the course is the special theory of relativity, together with a cursory review of the general theory of relativity and cosmology. The topics are theoretical and abstract; only brief discussions of experimental results are included to motivate the theoretical development. While the special theory of relativity (or special relativity) can be said to be important for various areas of physics, the general theory (or general relativity) and cosmology are typically considered more specialized topics, not included as mandatory material in most physics programs. Thus, the purpose of those latter parts of the course is mainly to give the students a flavor of the topics, perhaps motivating them to take specialized courses later.

The educational reason for improving the course

The teaching methods that have been used in the course are traditional, with lectures in front of a blackboard (or recently, a whiteboard on Zoom). I would like to develop this into a more interactive, engaging approach. Relativity is often a mind-bending subject of physics, and I would like the students to actively partake in discussions of the content during class. This would likely improve their comprehension of the topics; indeed, much of the course deals with concepts that are not necessarily mathematically challenging (as may be the case in other areas of physics) but conceptually challenging. Discussing these topics with your peers is one of the best ways to properly grasp them. That interactive learning can be more effective has been shown in various studies as well; see e.g. [Deslauriers et al., 2011]. Moreover, active engagement has also been linked to higher retention [Wilcox et al., 2020].

More detailed description of the course

The course is often taken by first or second year physics students. Pre-requirements consist of the mathematics course "Linear algebra and complex numbers" (BSMA1001) or similar knowledge on basic linear algebra, matrix and vector calculus, Taylor series, derivation, and integration. Also recommended are the physics courses "Interactions and bodies" (BSPH1001), and "Matter and interactions" (BSPH1002). The students should thus have mastered the mathematics relevant for special relativity, although typically some repetition of key results is useful in the first weeks of class. The students taking the course are in general interested in physics, and relativity is a topic that tends to engage with its counterintuitive but fascinating implications.

The treatment of special relativity requires relatively straightforward mathematics, the difficulties being more of a conceptual kind. A full treatment of general relativity, on the other hand, requires mathematics much more advanced than the students typically master. Thus, focus must be on the conceptual parts of the subject, since there is a limited range of calculations the students can perform themselves. Cosmology, meanwhile, uses results from general relativity at the outset, as well as results in statistical physics and quantum mechanics. Here too, focus is on the “big picture”, e.g., recounting the story of the Big Bang, the large-scale structure of the universe, and its energy contents, without going into any detail.

The treatment of special relativity is thus quite detailed and complete, the goal being that the students acquire a solid qualitative understanding and as well as the ability to perform quantitative calculations, which will be important for more advanced courses. For general relativity and cosmology, on the other hand, the goal is for the students to be able to recall and summarize the foundational ideas and some important results, seeing how they fit into the field of physics.

The course itself is typically quite small for an undergraduate physics course, with about 10 students. This makes discussions and various interactive activities fairly feasible (at least in theory).

Intended learning outcomes

As previously mentioned, the course is theoretical in nature. As a part of the Bachelor’s program in Science, it is mainly of direct use for those students who are interested in continuing their studies in theoretical physics. However, it is also valuable for all students to have a general understanding of relativity and cosmology, and how they fit into physics as a whole. The intended learning outcomes (ILOs) are of the scientific/knowledge type as opposed to skill-related. For the section on special relativity, the goals involve *functional knowledge*; the students are expected to understand this theory at a deep level and be able to use it to solve introductory problems from, say, particle physics. For the sections on general relativity and cosmology, which are more advanced topics and are allotted less time, the goals are mostly limited to lower-level *declarative knowledge*. We now state the specific intended learning outcomes:

At the end of this course, the students will be able to

1. explain the relativity of time and space according to special relativity.
2. analyse physical processes in different inertial frames by applying the Lorentz transformation.
3. use four-vectors and the conservation of energy and momentum to solve introductory particle physics problems.
4. summarize the foundations of general relativity (e.g., the equivalence principle)
5. recognize a few important metrics and use them to calculate simple physical observables.
6. summarize the big bang model of the early universe.

Out of these, the first three concern special relativity, and contain higher-level verbs from Bloom’s taxonomy [Bloom et al., 1956]. Meanwhile, 4-5 and 6 concern general relativity and cosmology, respectively, and contain lower-level verbs.

Timeline

The course is given during one period of the academic year, meaning seven weeks of class time. The 5 study credits that the course is worth translates into a workload of about 135 hours. There is a large amount of material to be covered in this brief time. This typically becomes a significant limitation for the treatment of general relativity and, to an even greater extent, cosmology. The latter subject is typically confined to the last course week, at which point students are already beginning to set their sights on their final exams.

In more detail, the schedule, together with topics and particular teaching methods, will be as follows:

- Week 1: Introduction, Galilean relativity, Einstein’s postulates, special relativity.

- Week 2: Special relativity: Spacetime diagrams, time dilation, length contraction.
- Week 3: Special relativity: Spacetime and causality, 4-vectors. Lectures, exercises.
- Week 4: Special relativity: Energy, momentum, and applications to particle physics.
- Week 5: General relativity: Equivalence principle, gravity as curvature of spacetime.
- Week 6: General relativity: Schwarzschild metric, black holes.
- Week 7: Cosmology: The expanding universe and the Big Bang model.

Teaching methods and planning of the learning process

In the past, the foundation of the course has been **weekly lectures** (2x90 min) of a traditional format, with the teacher lecturing continuously with the aid of a blackboard or a slideshow. This structure will remain, but with the aim to break up the traditional lecture format into a series of shorter activities, forming a more interactive, engaging, and constructively aligned whole.

To begin with, the students will be assigned weekly pre-class assignments involving reading material, educational videos (from e.g., Minute Physics and Khan Academy, discussed below, or pre-recorded by the lecturer). The understanding of this material will be assessed in small, graded quizzes (e.g., on Moodle) due before the start of class, as well through ungraded questions at the start of class. Such ungraded in-class questions will also be used to check retention of material from previous lectures, and to activate students and gauge their understanding in real time during the duration of the class. The students will be able to respond to the questions either directly or using online tools such as Flinga (especially for larger class sizes).

In general, the goal with the lectures will be to break up the previously continuous sessions into slots of approximately 20-minute length, as student concentration typically lowers dramatically after this time [Bligh, 1972]. The replacing activities include the previously mentioned in-class questions, which can also be formatted as group activities of 2-4 students discussing among themselves. An interesting alternative to such “quizzes” is **minute papers** *[*Biggs & Tang, 2011 p. 143], where students exercise explaining new concepts in writing.

Furthermore, parts of the lectures will be organized as **flipped classrooms**, see e.g., [Lasry & Dugdale 2014] or www.flippedlearning.org. The idea is to move direct instruction and knowledge transfer outside the classroom, meaning the individual student is asked to, e.g., read material or watch educational videos on their own. In class, focus can then be put on discussing topics the students find complicated or particularly interesting. Furthermore, some class time will be used to *apply* the theory by solving problems similar to those that can appear on homework assignments or in the final exam. The goal of the flipped classroom approach is to use in-class time more effectively, encouraging deeper learning by having the students discuss and work directly with new topics. It will be mostly used in the first 4-5 weeks of the course, when the topic is special relativity and the intended learning outcomes involve higher levels of Bloom’s taxonomy.

Beyond the structure of the weekly lectures, an important new element will be peer instruction in the form of **student presentations**. The idea is for the students to practice both *researching* and *explaining* physical concepts to their peers, as well as practice their presentation skills. This will be done in groups of 2-3 students. The lecturer will provide the groups with a list of suggested topics within the vast range touched on in the course, from which the students choose one. Groups are also allowed to suggest their own topics, although they may be rejected by the lecturer if they are too remote from the course contents or otherwise not appropriate. The groups are then tasked with researching these topics and preparing a pedagogical presentation that will be given to the rest of the class during a special session with compulsory attendance. The presentation should be 15-20 minutes long.

Another previous foundation of the course, which will remain with some modifications, is the weekly **exercise sessions** (2h). These sessions are led by a teaching assistant, typically a more senior student who has taken the course in the past. Their format is already quite interactive, being focused on the weekly homework assignment. These assignments consist of a range of problems that have the students apply the knowledge acquired from lectures and pre-class assignments. The teaching assistant will begin the exercise sessions by going through important and difficult points of last week's assignment, and then let the students work (together or individually, as the students prefer) on the coming one, while being available for questions. The assistant will also be encouraged to interrupt the session if they observe several students having the same issues; these issues can then be clarified for the whole group at once. In solving problems in front of the class, the assistant will furthermore be encouraged to use *think-aloud modelling* [Biggs & Tang 2011 p. 144], as this can help the students gain intuition on how to approach similar problems themselves.

Concerning **educational technologies**, the course will employ Moodle to distribute information (including pre-class reading and homework assignments), for handing in homework, and for conducting minor quizzes. Moodle can also be set up to include discussion forums, either class-wide or for smaller groups. If the students are so inclined, they are also free to use WhatsApp or similar apps to coordinate group work. During classes, websites such as Flinga can be used to collect real-time feedback, questions, and answers from students, which is particularly useful for larger class-sizes. If the course is forced to be conducted remotely, a video conference tool such as Zoom will be used. Traditional lecturing segments will then make use of online whiteboard tools such as Miro (www.miro.com).

More particularly for this course, there exists a range of freely available online resources aiding the explanation of concepts in relativity theory. Sites such as www.spacetimetravel.org contain a range of animations visualizing relativistic phenomena such as length contraction and the bending of light near a black hole. Well-made video series such as Minute Physics (https://youtu.be/1rLWVZVWfdY) and Khan Academy (https://www.khanacademy.org/science/physics/special-relativity) provide solid material for e.g., pre-class assignments (including the flipped classroom segments).

Assessment of the learning process

The pre-class and in-class quizzes will be used to assess the learning of reading assignments, as well as scanning for difficult concepts during class. This applies for the minute papers as well, which can probe understanding in slightly more detail than regular questions.

The weekly problem sets, which are the focus of the exercise sessions, will assess the ability to do computations (relevant for learning goals 2, 3, and 5) as well as the ability to briefly explain and summarize concepts in writing (relevant for learning goals 1,4, and 6). These will be distributed and returned through Moodle and graded by the teaching assistant. The teaching assistant will be instructed to convey common issues on problem sets to the lecturer.

The student group presentations will assess the ability to explain select concepts in more detail and depth, as well as the more general abilities of working together and collecting information independently. In practice, they will be assessed using peer assessment; the students will be asked to (anonymously) grade each other's presentations.

Lastly, the course will have a final exam, which will be intended to address all learning goals to some extent, although most focus typically ends up being on calculations, complemented by brief essays explaining concepts. This will be graded by the lecturer.

As usual, the course is graded on a scale from 0 to 5. The grade will be set by a combination of the pre-class quizzes, problem sets, student presentations, and final exam. In more detail:

- Pre-class quizzes – 10%
- Problem sets – 30%
- Student presentations – 20% (equal grade for all in the group except in exceptional circumstances)
- Final exam – 40%

Workload

The total workload for the 5-credit course should be about 135 hours. This time is roughly divided as follows:

- Lectures, 28 hours.
- Exercise sessions, 14 hours.
- Student presentations, 14 hours (including presentation and preparation).
- Working on weekly problem sets, 24 hours.
- Pre-course assignments and quizzes, 30 hours (including the reading of easy and difficult introductory texts, watching educational videos, etc.).
- Rehearsing course contents (including preparations for final exam), 25 hours.

The teacher's workload:

- Preparing the lectures, 42 hours.
- Giving lectures, 28 hours.
- Preparing homework assignments, quizzes, and final exam, 14 hours.
- Administrating student presentations, 5 hours.
- Assessing final exam, 6 hours.

Evaluation of the plan and reflection

The plan significantly improves on the previous version of the course, by making it more interactive and aligned. The lectures are overhauled, transforming from a traditional format to a mix of more engaging teaching methods. The teaching/learning activities and assessment are aligned with the learning goals. Flipped classrooms and other active teaching methods are particularly suitable for the higher-level ILOs associated with the special relativity-part of the course. The student presentations also encourage deeper learning by having the students research topics in groups and then explaining them to their peers.

The plan supports student motivation; in particular, the student presentations allow students to delve more deeply into a topic of their interest. The flipped classroom format that will be partially used also allows students to discuss topics of their own choice that they find interesting during class.

The workload has been estimated to be appropriate for the 5 study credits, as discussed above. For the teacher, the workload does significantly increase as compared to the previous version of the course, as can be expected. However, much of this increase stems from preparing new activities during lectures (e.g., quizzes and problems to work on during the flipped classroom sessions). After the first reworked class has been completed, following instances should involve a more reasonable workload.

Educational technologies are utilised both to streamline course tasks, to assess student understanding and retention before and during lectures, and to convey new concepts and ideas.

References

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