Hands-on with *Relativity Lab*: a simulation environment for special relativity in secondary education

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Abstract. The theory of special relativity is a notoriously difficult learning objective, especially in secondary education. Relativistic phenomena are counter-intuitive and very remote from everyday experience. Moreover, it is impossible to observe relativistic effects in practical experiments. We designed an online simulation environment, called *Relativity Lab*, in which students can construct and observe virtual relativistic experiments. A team of researchers and teachers collaboratively designed, performed and evaluated a three-lesson series centered around the use of *Relativity Lab*. In this workshop, participants are invited to experience *Relativity Lab* hands-on, with the aim of embedding *Relativity Lab* in their own teaching practice.

Introduction

Einstein's theory of Special Relativity (SR) is among the most iconic and excising topics in physics. Learning about SR's radical departure from classical mechanics supports a better understanding of scientific reasoning and improves students' attitude towards physics. This is why SR is an increasingly popular topic in secondary physics education worldwide [1]. Bringing SR to the classroom, however, is a difficult endeavour for students as well as teachers. Relativistic phenomena, such as time dilation, are counter-intuitive and very remote from every day experience. Moreover, it is impossible to explore these concepts by means of practical experiments. We have developed an online simulation environment, called *Relativity Lab*, in which students can construct virtual relativistic experiments themselves [2]. A key feature of *Relativity Lab* is the possibility to select the inertial frame from which the simulation is rendered. This allows for comparison of measurements in different inertial frames. See Figure 1.

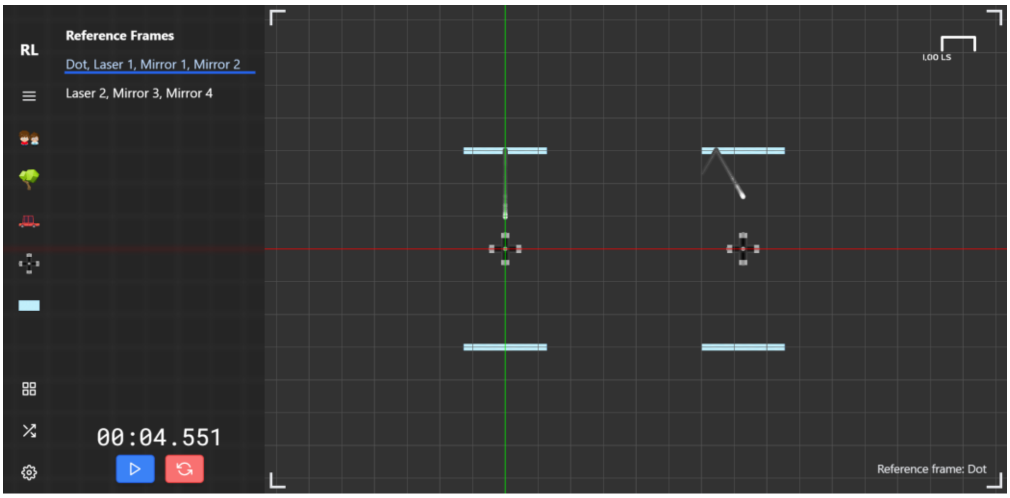

Fig. 1. A simulation of time dilation of a light clock in *Relativity Lab*. In the currently selected inertial frame, the left light clock is stationary while the right light clock is moving. The period of the moving light clock is dilated.

Lesson design

A team of three researchers (the authors) and three Dutch secondary school physics teachers collaboratively designed, performed and evaluated a lesson series that serve as an introduction to

SR. The developed lesson series consists of three 90-minute lessons, each focusing on a central learning objective through a combination of plenary discussion and simulation activities. See Figure 2 for a schematic overview of the lesson series. Each lesson starts with the introduction of a thought-experiment to sparkle curiosity and activate prior knowledge. The three simulation activities were designed to facilitate inquiry-based learning: students are asked to predict the outcome of a thought-experiment, and subsequently test their prediction by constructing a simulation in *Relativity Lab*. The first lesson focuses on non-relativistic relative motion. The main learning objective is to familiarise students with the concepts of events and inertial frames. Spacetime diagrams are used to represent the observed simulations graphically. In the second lesson, the invariant speed of light is introduced. Subsequently, students perform a simulation activity in that reveals that the invariant speed of light results the relativity of simultaneity. This clearly demonstrates a conceptual leap between SR and classical mechanics. The final lesson focuses on the concept of time dilation. Students perform a simulation in which they explore time dilation of light clocks. Finally, they are asked to apply the concept of time dilation to a real-life experiment. Each lessons ends with an *exit card* in which students are asked to generalize and transfer their findings. Preliminary analysis of the exit cards indicates that the inquiry-based simulation activities prompted students to explicate their pre-existing assumptions about relative motion and to reflect on them critically.

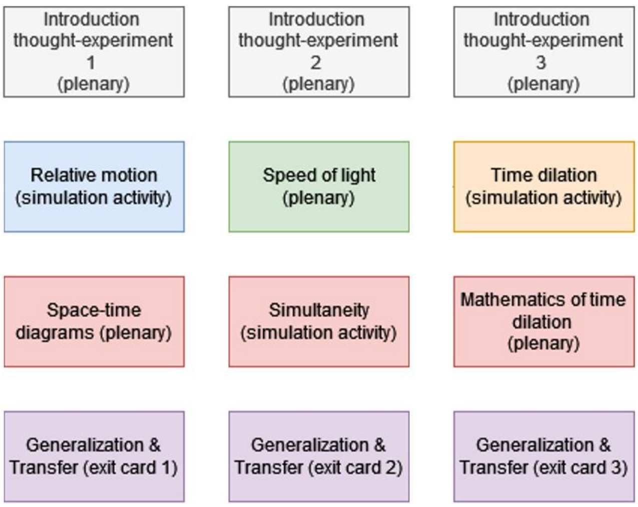

Fig. 2. A schematic overview of the three-lesson series.

Workshop activities

During the workshop, the participants are invited to experience *Relativity Lab* hands-on by performing the designed simulation activities themselves. The design team will introduce key features of the teaching material and share their personal teaching experiences. While the workshop aims at supporting teachers in implementing *Relativity Lab* in their classroom practice, it also serves as a general example of the use of simulation tools in the physics classroom.

References

[1] P. Alstein, K. Krijtenburg-Lewerissa, W. R. van Joolingen, Teaching and learning special relativity theory in secondary and lower undergraduate education: a literature review. *Physical Review Physics Education Research* **17**(2) (2021).

[2] P. Alstein, K. Krijtenburg-Lewerissa, W. R. van Joolingen, Designing and Evaluating Relativity Lab: A Simulation Environment for Special Relativity Education at the Secondary Level. *Journal of Science Education and Technology* (2023) 1-14.