Designing an open-ended simulation tool for special relativity education at the secondary level

Paul ALSTEIN, Kim KRIJTENBURG-LEWERISSA and Wouter VAN JOOLINGEN

Freudenthal Institute, Utrecht University, P.O. Box 85170, 3508 AD Utrecht, Netherlands

Abstract. We report the design and first evaluation of an open-ended simulation tool for special relativity education at the secondary level. The simulation tool, named *Relativity Lab*, is aimed at supporting students in performing and evaluating thought experiments, by constructing simulations from scratch and viewing the outcomes from different frames of reference. We performed a usability test (*N*=11) in which students were asked to perform thought experiments in a predict-observe-explain format. Preliminary findings indicate that students are able to construct simulations correctly and that the session helped them to imagine thought experiments more clearly.

Introduction

Special Relativity Theory (SRT), representing a fundamental change in our understanding of space and time, is an attractive topic to introduce secondary school students to the world of modern physics [1]. As a consequence, an increasing number of counties have implemented SRT into the secondary school curriculum. The level of secondary education calls for a conceptual approach to SRT, in which abstract concepts are expressed through the use of Thought Experiments (TEs), rather than mathematical or geometrical formalism [2]. TEs in SRT always require students to view motion from different frames of reference, while respecting the invariant speed of light. This has been shown to be notoriously difficult for secondary school students [3].

Computer simulation tools have the potential to support students in performing and evaluating TEs. A number of simulation tools for SRT are currently available [4], however they do not allow students to construct simulations from scratch, thus limiting its full education potential. We aim to contribute to this discussion by developing an open-ended simulation tool, named *Relativity Lab*, in which students can freely construct and observe simulations in a simplified virtual environment. In this contribution, we describe the main design features and present preliminary findings of student feedback.

Design

Relativity Lab is a two-dimensional virtual environment, in which the user can construct simulations by placing virtual objects, represented by icons, onto a grid. The velocity of each object can be assigned relative to the currently active frame of reference. Running the simulation presents the user with an animated visualisation of the trajectories of the objects in the currently active frame of reference. At velocities approaching the speed of light, the user is able to explore simulations that express the relativity of simultaneity and time dilation. A screenshot of *Relativity Lab* is shown in Figure 1.

Basic design features were formulated based on a literature review, student interviews and classroom observations. One of the main design features is that reference frames are represented as layers, each layer corresponding to the set of objects that are in rest in that reference frame. As a consequence, there is no necessity for separate observers. We hypothesise that this level of abstraction helps students to recognise that the time and position of an event in a particular frame of reference should not be associated with an observer's position.
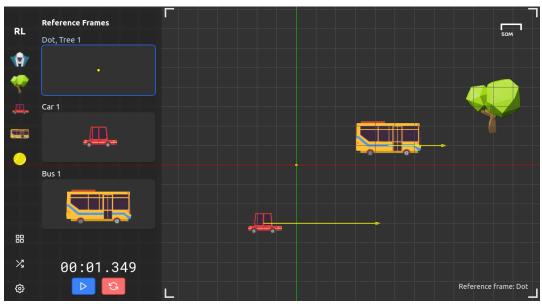
Fig. 1. Screenshot of Relativity Lab.

Preliminary findings and outlook

We performed a usability test with pairs of secondary school students ($N = 11$) with no prior instruction to SRT. In these tests, students were asked to perform 3 simple non-relativistic TEs in a predict-observe-explain format. At the end of each session, students were asked to reflect on the session and to formulate suggestions for improvements. Although two pairs of students could not manage to formulate clear predictions, all students were able to construct simulations correctly. Students' feedback indicated that the session had helped them to imagine TEs more clearly. For example, one student noted "*You can see it happening. Otherwise, it's just in your head. Its always better if you can really see something, if you can really have an image*". Another student noted: "*Sometimes you don't expect something and this program showed you that it is actually different. And then you can explain that using this program*". During the usability tests, it became clear that students were confused by the fact that there was no unit of distance. Students also found it difficult to pause the simulation at relevant times, such as a collision. In a redesigned version of *Relativity Lab,* improvements have been made to address these issues, among others.

The next step in *Relativity Lab*'s evaluation is to perform a similar intervention with relativistic TEs, such as the famous *Einstein's train*. From these results, we hope to prove *Relativity Lab*'s potential to address some of SRT's most robust learning difficulties.

References

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