A Slower Speed of Light: Developing Intuition about Special Relativity with Games

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ABSTRACT
The effects of special relativity are not immediately observable in our everyday lives, so we tend to lack an intuition about them. For this reason, special relativity is often considered too abstract a concept for introductory physics courses. Games may provide one solution to this problem. In this paper, we introduce *A Slower Speed of Light*, a game by the MIT Game Lab to help students understand and visualize these complex phenomena by artificially lowering the speed of light to walking pace. We also discuss future directions for the game, as well as the release of OpenRelativity, an open-source relativistic toolkit for Unity3D.

Categories and Subject Descriptors
K.3.1 [**Computers and Education**] Computer Uses in Education; J.2 [Physical Sciences and Engineering] Physics

General Terms
Design, Theory

Keywords
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1. INTRODUCTION
So-called Modern Physics—Special and General Relativity as well as Quantum Physics—is frequently left out of standard introductory physics curricula or pushed into the last two weeks of courses because it is deemed "too abstract."

The reason is that the constants governing their strengths (speed of light *c*, Planck constant *h-bar*, and the Gravitational Constant *G*) are so high (in the case of the speed of light) or low (in the case of the Planck and Gravitational constants) that the phenomena are not immediately observable in our everyday experience. If those constants were different, we would grow up with relativity and quantum physics, and their effects would be as familiar as the effects of Newtonian physics. This lack of intuition leads to number of student misconceptions, which particularly in Special Relativity have been well investigated [1, 2, 3].

The idea of our project is to create a relativistic environment in which students can develop this intuition. In the first phase of our project, we developed a game environment in which the speed of light *c* is lower than in nature.

2. VISUALIZING RELATIVITY
The idea of visualizing Modern Physics and expanding it into the human-experiential scale is not new. In fact, it often was an integral part of the development of the associated theories.

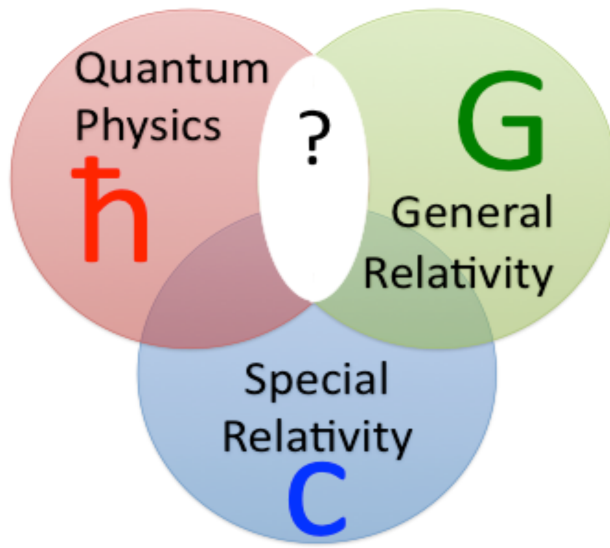

Figure 1. Realms of Modern Physics

"What would you see if you were riding a beam of light?"—This thought experiment, which Einstein reports to have "conducted" at the age of 16 [4], of course has no sensible answer: as Einstein published a decade later, you could never reach the speed of light [5]. However, it does make sense to ask what you would see if you were traveling close to the speed of light, and one of the first physicists to embark on this effort was George Gamow in *Mr. Tompkins in Wonderland* [6]. His protagonist is speeding on a bicycle through a city where the speed of light is lower, thus ingeniously taking advantage of the fact that Special Relativity scales with v/c: for it to kick in, you either have to move very fast (in rather unfamiliar territory), or light has to be slow (in which case Special Relativity kicks in at everyday velocities in everyday situations). Gamow provides drawings of what Mr. Tompkins and people at the curb would see in this slow-light city; at least, what they would see if one only took into account two of the effects: length contraction and time dilation.

Gamow unfortunately neglected, or was unaware of, some nagging issues that were first identified by Lampa: what you would *see* is different from what you would *measure* [7]. Gamow's "simulated" world is similar to other computer simulations of Special Relativity that have been developed for teaching purposes, such as RelLab8 and PhysLets for Special

Relativity [9]. These simulations use a compiled picture from simultaneous observers everywhere in the coordinate frame. In other words, they illustrate what you would measure, not what any observer at any location could see. Confusing these two "views" is one of the major hurdles toward understanding Special Relativity [2], and for the longest time was apparently not even fully appreciated by experts like Gamow.

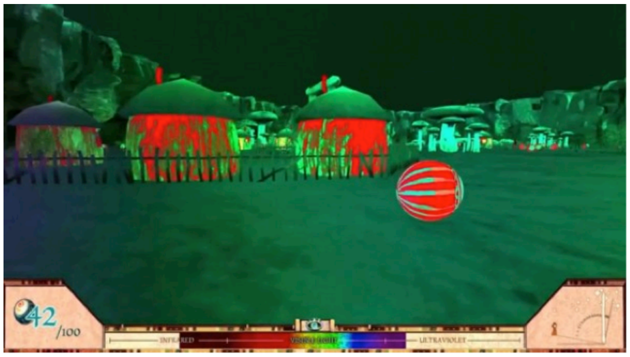

Figure 2. Screenshot of *A Slower Speed of Light*

It took almost two decades after Gamow before the topic would get picked up again, namely by Terrell [10] and Penrose [11], this time taking into account the finite runtime of light: light that was emitted at a farther distance actually comes from the past. (This is the same effect that, on an astronomical scale, leads to the fact that looking out into space actually means looking back into the history of the Universe). As a result, length contraction is not always visible as a contraction, and interestingly, spheres always appear spherical. In addition, there are two more effects need to be taken into account to get the full picture: Doppler Shift and Relativistic Aberration ("Searchlight Effect"), leading to phenomena like the familiar "Red Shift" and the fact that more photons hit you from the direction into which you are traveling.

Illustrating all of these effects in concert requires more than the pencil and paper of Gamow: it takes a computer to get it right. Foundations for this visualization were laid four decades later by Weiskopf [12], which led to a number of computer-generated movies [13], including (in reference to Gamow) a bicycle ride through the German city of Tübingen [14]. These visualizations are available online [15], as well as on DVD [16].[16] Due to the high computation requirements, the viewer cannot control the movement. However, the asynchronous nature of these visualizations allows for expanding beyond Special Relativity into the computationally even more intense General Relativity realm [17].

The first interactive first-person visualization of relativity, Real Time Relativity [18], has since been used for teaching purposes at the Australian National University and elsewhere [19]. Their implementation does not slow down light, but moves the viewer into space, where he or she actually travels fast. However, the movement of the first-person viewer is completely controllable, and different effects can be switched on and off in order to see their visual impact. Their engine does not include third-party movement, since that poses significant challenges in tracing the "history" of an object to find out when it would have emitted photons that are momentarily visible to the viewer.

Another approach was taken in a virtual billiards game that tracks the motion of a limited number of third-party objects, and takes place in a virtual reality cave. An advantage of this approach is that the same scenario can asynchronously be viewed from different frames-of-reference [20]. The current version this game does not take into account Doppler and Searchlight Effects.

3. OPEN RELATIVITY AND 'A SLOWER SPEED OF LIGHT'

Recently, our group developed a game based on a new first-person relativity visualization engine (released as OpenRelativity), which includes simple third-party movement: third-party objects can be generated and destroyed at fixed points in the environment, as long as they are moving uniformly along a straight line in-between. This game, *A Slower Speed of Light*, is a first-person game prototype in which players navigate through a 3D space while picking up orbs that reduce the speed of light in increments. A custom-built, open-source relativistic graphics code allows the speed of light in the game to approach the player's own maximum walking speed.

The visual effects of Special Relativity gradually become apparent to the player, increasing the challenge of gameplay. These effects, rendered in real-time to vertex accuracy, include the Lorentz Transformation, Light Runtime Effects, the Doppler Effect, and Relativistic Aberration ("Searchlight Effect").

A Slower Speed of Light is available as a free download for PC, Mac and Linux [21], and we are encouraged by our early success in distributing the game. For example, game's video trailer alone has been watched more than 625,000 times on YouTube [22], and the game itself has already been downloaded more than 78,000 times (68,000 Windows downloads and 10,000 Mac downloads). The game's success lends credibility to the idea that producing free, easy-to-play games may provide a viable alternative method to disseminating scientific research to the public.

In addition to this stand-alone game, we released the visualization engine OpenRelativity [21], a toolkit for the Unity3D game engine. OpenRelativity provides the public (and, in particular, game designers) with a set of tools for simulating the effects of traveling near the speed of light, demonstrated by *A Slower Speed of Light*. Our hope is that releasing this engine as an open-source project will encourage not only a better understanding of Special Relativity, but also lead others to produce novel game designs incorporating these effects.

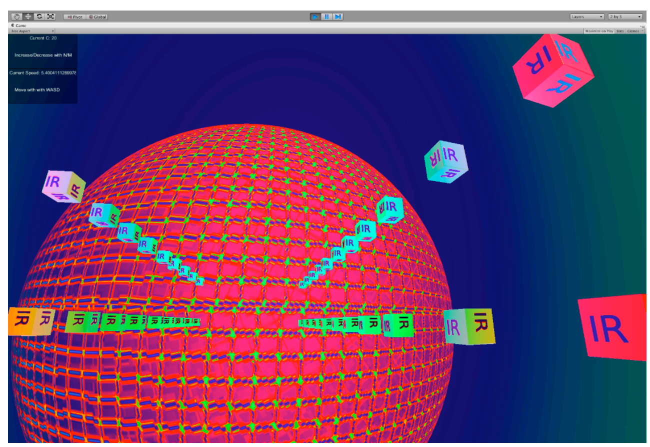

Figure 3. OpenRelativity offers support for custom infrared (IR) and ultraviolet (UV) textures in the Unity3D editor.

4. FUTURE WORK

We hope that the current game is only the first of a number of games based on OpenRelativity, some of which could be "lab experiments" or "hands-on" components in university physics courses. Today's students are quite used to operating in environments with modified and changing representations of physics, such as in *Portal* [23] or *Quantum Conundrum* [24], so we have high hopes that they would find their way through an environment in which the physics is actually altered *correctly*.

Of particular interest would be a level editor, in which predefined relativistic objects can be assembled to generate new educational challenges and puzzles along the lines of the famous barn-pole "paradox" [25]. This level editor, which is similar to level editors built into games like *Portal*, allows players (in our case both instructors and students) to assemble predefined static and functional objects into new scenarios. In addition to the existing game objects, new objects could include clocks (similar to *Real Time Relativity*), switches with delayed-action cables, triggers, doors, controlled-release marker objects, measurement tapes, explosives, and others. The editor makes the game engine accessible to other educators for the development of new curricular materials without any knowledge of programming.

We will also pre-construct a number of scenarios, which readily integrate into existing curricula. The general framework and foundation for this integration will be provided by Scherr's extensive study of student understanding of Special Relativity, as well as the associated tutorials developed at the University of Washington [2]. We will also build on curricular materials developed around *Real Time Relativity*, while taking advantage of the 3rd-party moving objects and the to-be-built level editor in our engine.

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