Modern Physics for 5th and 6th Grade Students

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ABSTRACT

I taught modern physics to several classes of fifth and sixth grade students over the course of a private school's summer program. My goal was to expose kids to topics in physics I find most wonder-inducing and interesting in hopes that I could inspire a life-long love of physics in many of them. Though it is impossible to see long term effects yet, I felt my class was successful in helping students to enjoy and understand difficult subjects. While researching for this paper, I stumbled upon the Einstein-First Project, which similarly emphasizes Einstienian physics for younger students. After I give a thorough explanation of my own course, I will review some of the literature related to the Einstein-First Project, emphasizing the benefits of teaching children modern physics.

INTRODUCTION

Most elementary students, if they are exposed to physics at all, learn basic mechanics. Few elementary students learn any modern physics, unless it is in movies, tv shows, or books. However, research into elementary physics education has shown that not only is it possible to teach elementary students modern physics, in some cases it might even be preferable. (9)

The summer of 2021, I taught physics in California to fifth and sixth grade students as part of their summer program. The school gave me full creative liberty to plan and deliver curriculum as I saw fit. In fact, they only told me to teach "science," and gave no direction on what specific science I was to teach. There was a prepared anatomy curriculum which I could have used, but since most fifth and sixth graders might know more than I do about anatomy, I decided to create my own course.

As an applied physics major, I knew I definitely wanted to teach physics. The school, like most schools, had taught physics courses before in their summer program, but each had emphasized simple mechanics, buoyancy, and other ostensibly "age-appropriate" physical principles. As I considered what exactly I would teach, I decided to avoid such physics and focus on things that interested me at their age. Although I had not done any research into scientific papers on teaching modern physics to younger students yet, I knew that I was interested in modern physics and elementary school, and I figured there was a way it could be taught to them.

I fell in love with physics in fourth grade, when I read a biography of Albert Einstein. Concepts like time dilation, general relativity, and the debate around "spooky action at a distance" blew me away. Although my understanding at the time was surface level at best, the ideas sparked my imagination and kindled a lifelong fascination with physics. Unfortunately, in high school I was bored by basic mechanics. I took physics before calculus, so although I could memorize the equations they gave me, I did not understand where they came from or why they worked. I felt like physics was nothing more than plugging in numbers and solving for x–a math class with more story problems than usual. My love for physics was not rekindled again until my freshman year of college, when I started reading popular science books. I rediscovered the beauty of physics when I focused on things that spurred my own imagination, creativity, and wonder. Students have lots of time to memorize and apply problem solving techniques, but too often, they are not given enough of an opportunity to fall in love with what makes a subject fascinating. School can sometimes feel like drudgery, an endless list of tasks and check marks to get a grade. School becomes dancing without music. I think the music of physics is the fascinating, often counterintuitive, wonder it arouses.

Inspired by my own journey, I wanted to teach the kids things that would blow their minds. Many of these mind blowing topics have already bled into popular culture, albeit in a simplified or completely erroneous fashion (think *Interstellar* for simplified and wildly speculative general relativity, and *Ant-man* for erroneous quantum physics). I decided modern theoretical concepts, rather than forcing them to memorize Newton's laws, would do more to help the kids hear the music of physics than anything else–especially since it was just a short summer program.

I organized my course around the work of Einstein, including a summary of his life and achievements, the photoelectric effect, special relativity, and general relativity. Additionally, though Einstein was not involved, I did a lecture on the double-slit experiment. I am a theory guy, but I know some people prefer hands-on projects, so I also did five demonstration days alternating with the lecture day. These included: rockets made from paper and straws, balloons and static electricity, popsicle stick catapults, origami helicopters, and building structures out of straws. These also served to break up the lectures so students did not feel like everyday would just be sitting at a desk, something nearly intolerable for some kids during the summer.

After completing and teaching my course, I found the Einstein-First Project and realized the topics I taught aligned closely with some of the research accomplished by them. They seek to teach children physics by emphasizing Einstein's discoveries, with a similar philosophy to my own outlined above. In the Results and Discussions section below, I will give an overview of a few of their projects and the reported success.

My hope is that my experiences teaching and writing this report will be relevant in my life and the lives of those future educators who come into contact with my research.

METHODS

In the methods section, I will explain the school where I taught, my own background, my thought process in designing the course, and give an in-depth description of my curriculum. Establishing a solid context for my course will be helpful in showing why I thought it possible to teach these students modern physics, and why I believe I was successful.

Participants and School Context

The school I worked at is a small private institution nestled in the hills above Silicon Valley. The students are generally motivated, intelligent, and have some background knowledge of physics: many of their parents are engineers or employed in some other Tech/ STEM type field. Several times I was shocked by what the 5th and 6th graders already knew or how well they understood new concepts. One particularly bright student, the child of a parent with a physics degree, had even read a popular science book on special relativity and would frequently raise his hand to add interesting tidbits to what I was teaching. However, I knew that not all the students would be interested in a lecture-heavy class, as it was a summer program, and many of the other classes offered had much more of an emphasis on fun. The point of the summer program is not to help students catch up on material from the school year but rather to stir up interest in students and parents for full time enrollment. Many of the students do not attend the school normally and are coming during the summer expecting an enjoyable experience–it is a mix of a summer camp and summer school, but perhaps leans towards camp. Science at the summer program especially has a reputation as an activities based class with short lectures, exciting experiments, and interesting demonstrations.

Personal Background

My understanding of the context of the summer program comes from my own enrollment there as a child. When I took science, we made tin foil boats to see how many pennies they could hold before sinking, folded paper airplanes and had a competition for which could fly the furthest, and timed how long acetate took to burn through styrofoam cups. Though I do not remember much from science during the school year, science in the summer program has always been a highlight of my education. I wanted to make sure my students held similar fond memories.

My first summer back from my mission I got a job as an after-school counselor, facilitating sports, free reading time, and outdoor activities. Summer of 2020, they asked me to come back due to a shortage of teachers. Since I had done a good job as a counselor, they let me teach real classes, though they provided me with ready-made curriculums. After success in that position, in summer of 2021, they offered to let me design my own science class.

As mentioned in the introduction section, my goal for the class was to help students cultivate a lifelong love for physics. I know that physics can be mind-bogglingly fascinating, but many elementary and high school students think of it as nothing but an extension of their math classes–that was my own opinion of physics in high school. However after my mission, I read *Seven Brief Lessons in Physics* by Carlo Rovelli. The short book focuses on theories of modern physics that Rovelli believes are most beautiful and captivating. I agree with his choices. He writes about relativity, black holes, entropy, quantum theory, and even potential grand unifying theories. My imagination and curiosity were ignited and from then on, I could not get enough of popular science books. It did not take long before I switched to studying physics. Obviously, the math is still there, but with a better idea of how the math fits into the beautiful tapestry that is physics, math becomes a lot more fun. Yet without focusing on any math, I wanted to give the students something like the experience I had reading Carlo Rovelli's book.

Course Design

If I was teaching college or even high school students, I would have just used Rovelli's book as a textbook, taking lectures directly from the chapters, adapting them or adding to them as needed. But most of the book is too far above the average 5th and 6th grader's level, so I set about simplifying the material while keeping as much of the wonder as possible.

I was also interested in explaining physics that have already bled into popular culture ($E = mc^2$, special relativity, quantum physics), albeit in a much diluted way. I wanted to show the kids that even equations or concepts which are often portrayed in films as super complicated or esoteric can be understood. Hopefully, I would give kids the confidence to go out and research these things themselves. I wanted to bridge the gap between what kids already knew, and what they wanted to know, or did not even know they could know.

As such, I designed the lecture curriculum around Albert Einstein's discoveries. Everybody knows who he is, but it was not until I read *Seven Brief Lessons* that I understood what he had done, and just how incredible it all was. Based on the program schedule, I had five lectures to teach, so I decided to break down Einstein's major discoveries into five chunks–with one slight diversion into quantum mechanics. Because the topics were so complicated, I wanted to be as clear as possible. As Feynman taught, if you cannot explain something to a child, you do not understand it yourself.

I began by doing as much research into the topics as possible, breaking each down into its simplest parts. I wanted to teach as much as possible without getting math heavy or overcomplicated. I also wanted to teach everything as if the children had absolutely no background knowledge in physics whatsoever. I figured that the first time I explained something, kids would catch some of it, but not without significant gaps. I made sure to check understanding by asking questions, but I also knew students would need a lot of exposure to the complicated topics before grasping them. So every few slides I showed a good youtube video to review everything I had taught. I was careful to make sure the videos had no new information, as their purpose was to give the kids a short break from my voice and my whiteboard drawings, and an opportunity to fill in holes from what I had just taught. For further incentive to pay attention, every class ended with a jeopardy game based on the lecture content. The members of the winning team each got fun sized candies. I iterated through each child on each team, making sure everyone answered at least one question everyday. If I noticed one team had won two days in a row, I switched up teams to give other kids a chance.

With the other five days of class, I wanted to do activities. I tried to think up things that related to the lecture, but understandably, it was difficult to come up with realistic, cheap experiments or demonstrations that fit with relativity and quantum mechanics. After spinning my wheels for a while, I decided to take the activities in the opposite direction by working with more everyday physics. I felt this also would cater to the kids who were less interested in theory and more interested in the practical engineering aspects of physics. On the activity days, I spent about ten to twenty minutes explaining the physics behind a particular topic, then the rest of class (~thirty minutes) playing with or creating something related.

Below is a table with each lecture and activity in the order they were taught:

Lecture 1: Who was Albert Einstein?
Activity 1: Straw Rockets
Lecture 2: The Photoelectric Effect
Activity 2: Balloons and Static Electricity
Lecture 3: The Double Slit Experiment
Activity 3: Catapults
Lecture 4: Special Relativity
Activity 4: Helicopters
Lecture 5: General Relativity
Activity 5: Structures

Detailed Class Descriptions

Lecture 1: Who was Albert Einstein?

The first lecture covered the definition of physics, Einstein's life, and then broke down his famous energy equation into understandable terms. I explained what energy is, what mass is, and just how big the speed of light is. Without doing any derivations or how $E = mc^2$ comes from special relativity, I simply explained that we can think of mass as frozen energy, and that because of the speed of light, energy is very big, even in a small mass. Since all mass has tons of energy inside of it, if we figure out how to release that energy, we have a huge burst of energy. That is how nuclear power works. After explaining all this, I showed a brief video reviewing the meaning of $E = mc^2$.

From the first lecture, I hoped that students would understand for the first time something they had seen many times before. $E = mc^2$ is practically ubiquitous, but few people actually understand it. By simply explaining what the variables meant and the equations implications, my goal was to show students that physics does not have to be difficult or confusing. More than that, physics can be very interesting!

Activity 1: Straw Rockets

I began by teaching about Newton's third law. I showed a gif of astronauts throwing objects in space, graphics explaining kickback from a cannon firing, and a video on the third law. Then I showed the cross section of a rocket, and explained how the expulsion of fuel out the back provides enough thrust to lift the rocket off the ground, thanks to the third law. I wanted to make some sort of chemical rocket, but due to safety constraints, the children instead drew rockets on paper, cut them out, then attached a straw to the back. Blowing into the straw launched the rocket forward. Since propulsion did not come from the inside, the rockets did not work exactly like a real one, so I explained instead that when they blow in the straw, the third law reaction happens on them, as pushing the rocket away exerted an equal force on their face!

Lecture 2: The Photoelectric Effect

This was probably the most difficult lecture to teach, as the photoelectric effect is slightly less mind-bogglingly fascinating than relativity or the double slit experiment. But since it gave Einstein his Nobel Prize and led nicely into the quantum lecture, I thought it was useful to teach. I first explained what particles are, then explained that light is a particle called a photon. I explained that electrons are negatively charged particles. Most students already knew what electrons were, or at least had heard of them. I wanted very badly to give them a live demonstration with an electroscope, but they were too pricey to buy one and all my homemade attempts with tinsel, soda cans, aluminum foil, and a UV disinfecting wand failed, so I had to show them a video. After explaining exactly what happened, drawing pictures of electrons filling the electroscope and then being ejected, I explained that different colors (wavelengths) of light have more energy. As a demonstration, I had the students try to knock a paper towel roll off the front desk using just crushed up paper. I had every student throw as many crumpled up papers as they could at the roll to try to knock it over. But no matter how many pieces of paper were thrown, the roll remained firm. Finally, I had one student throw a dodgeball at the paper towel roll and easily knock it off. From this demonstration, I explained that the intensity (amount of balls) doesn't matter–only the energy (weight of the balls) does. Finally, I explained how the photoelectric effect plays into solar panels and showed a video to sum everything up.

Activity 2: Balloons and Static Electricity

This was the one activity that fit somewhat with the previous lecture. Since I had taught about electrons in the photoelectric effect, it was natural to explain static electricity at an atomic level and let the kids play with it. After a short explanation and video, I gave each kid a balloon, told them to rub it against their hair, and let them play. I gave them tin foil, pepper packets and paper plates, and showed them how static can bend water from a faucet.

Lecture 3: The Double Slit Experiment

I had to stay very surface level for this lecture. Basically, all I did was explain what happens when particles go through a slit and waves go through two slits. I explained the difference between waves and particles, then showed a video of both going through two slits. After making sure they could recognize if a pattern was made by a wave or a particle, I asked them to guess what they thought electrons might do. Most remembered that electrons were particles, so they guessed they would make two straight lines, just as normal particles would make. Then we watched a video showing what actually happened–a diffusion pattern. The kids were confused, but I told them it was only about to get worse. The experiment changes depending on whether or not it is measured! I asked the kids to guess why that might be, and their insightful answers ran the gamut of modern interpretations. More than one child suggested the particles were actually conscious, and behaved differently if they knew we were looking. Another suggested there was nothing weird going on, and the measurement device must interfere with the path of the particles. Without offering my own explanation (because I do not understand what is going on at all), I explained that this experiment was still a hot topic in science, with many different interpretations offered. I wanted to show the students that physics is alive and breathing, with new things to be discovered all the time!

Activity 3: Catapults

For this activity I explained potential energy generally, then explained how it applies in a rubber band or other objects. Then, using popsicle sticks and plastic spoons, we created catapults as a demonstration of energy transfer: energy from the sun grows plants which we eat for energy which we use to push the spoon down which flings a wad of paper across the room.

Lecture 4: Special Relativity

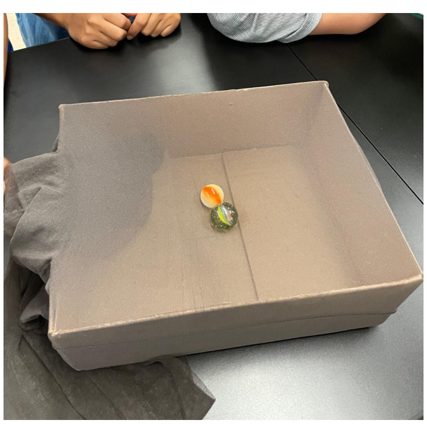
First I explained Newtonian relativity and why objects in a car all seem to go the same speed while things outside the car seem to move. Then I brought up the paradox Einstein solved: if light must always go the same speed, what happens to light when it is on the front of a train or some other moving object? I explained that since the light must still go the same speed, the length of the train must shorton! Without going in depth into the geometry of why that happens (it is hard for many college students), I just told them that when an object goes a significant portion of the speed of light, its length contracts. Then I explained that time dilates as well, meaning faster objects experience slower time relative to some rest frame. Again, I did not go into depth on why this was the case, just that it was. I showed them a video to sum it up, then had fun doing some calculations with them on how many years would pass on Earth if they traveled the speed of light for a certain amount of time.

Activity 4: Helicopters

For this activity, we brought back Newton's third law. I explained how rotor blades force air down, pushing the helicopter up. Then, I explained the four forces of flight and how a helicopter utilizes each. I briefly explained angular momentum and why a tail rotor is essential to maintain control. Finally, I taught the kids how to make origami helicopter blades and we dropped them from the top of our desks, watching how they fell slower than a paperclip due to upward thrust from the spinning wings.

Lecture 5: General Relativity

I finished the lectures with general relativity and black holes. I explained that this time, Einstein wanted to understand what gravity actually is, as even Newton admitted he did not know where it came from, just how it worked. I explained Einstein's thought experiment of the man falling from a great height, and how during his moments in the air it was effectively as if no gravity operated on him. I talked about how that led Einstein to realize that standing in an object accelerating upwards would feel the same as standing on a planet with comparable gravity. Einstein thus theorized that space is a moveable 4D material that shifts and bends when mass interacts with it. To demonstrate, I stretched nylon leggings across a cardboard box and pointed out how marble warped the nylon. The bigger the marble, the deeper the dent it made, and the more other



marbles were attracted to it. This is why objects with more mass have more gravity. What happens if an object is so massive it breaks the nylon? I asked, as I pushed a pencil deep into the leggings. A black hole! Many of the students could guess this. I explained how black holes are objects of immense mass condensed into an infinitesimal point, and how no one really knows what happens at the center of one. Then I got to time warping, and how the bending of space requires that time moves slower in areas of greater gravity. To illustrate this, I put a pencil across the nylon to represent a beam of light, before putting a marble next to the pencil. Now the space was curved, meaning the pencil (light) had to curve to get where it was going. The curve meant more distance existed between the light and its final destination, but light always must travel the same speed. If the distance is greater but the speed must increase, then time must slow down! I showed them a couple clips from *Interstellar* to illustrate how time spent close to a massive object (black hole) actually slows time down relative to people not near that object.

Activity 5: Structures

As this was the last day of class, I gave all the students candy, spent a little bit of time explaining structures and why a triangle is the strongest shape, then let the kids work alone or in groups to build towers out of straw and tape. At the end of class, we had a competition to see whose tower could withstand the most weight.

Summary

I taught at a small private school with motivated and intelligent students. I felt that the students would be able to handle modern physics, so I designed a course that emphasized principles I felt most interesting and important. I alternated lecture days with activity days to make sure all the students had something to look forward to, even if they were not fans of theoretical physics. In all, there were ten class periods with five foundational principles of modern physics and five activity days based on some principle of physics that lended itself well to a project.

RESULTS AND DISCUSSION

Although I did not complete a traditional research driven capstone project, I will discuss my own perception of how the students understood and enjoyed the class. Furthermore, I will explain some problems with elementary science education, then give a brief survey and analysis of educational literature on teaching modern physics to elementary school students, especially emphasizing the Einstein-First Project, and how a modern physics curriculum might resolve some of the problems in science education.

Observations

I felt that my class was successful in giving students an age-appropriate background in modern physics and hopefully in sparking a fire that will carry some of them into STEM related fields–or even physics!

From what I could tell, there were three groups of kids in the class. The smallest group, though perhaps the most outspoken, already liked physics and had lots of comments and questions which showed at least a basic understanding of what I already taught. The second and largest group was made up of students who knew nothing or little about physics, but were still willing and eager to learn. The third group was made up of the kids who just did not want to be there. Not surprisingly, this group was likely to be found in the last period of the day.

It was easy to get the first group of kids to like my class. Some of them even expressed that this was their favorite class at summer school. Many had parents with physics or engineering degrees and had already talked or learned about modern physics at home. These students already knew how mind blowing it could be, and they thoroughly enjoyed filling in gaps and building on what they already knew. These students would try to find me at break times and ask further questions about physics. For anyone who has taught before, these are the students that make the class most fun!

I will jump to the third group now and focus on the second group last. I like to think that even children in the third group enjoyed my class some days–if not everyday. Lecture days were understandably tough for kids who wanted to be home or doing something else. Usually, the promise of candy for the winning jeopardy team kept some of them focused, but for the most rowdy, even this did not calm them down. Luckily, keeping unruly students under control was never more complicated than moving them away from their friends. And even the most uninterested kids had fun the days we made rockets, catapults, and helicopters. The static electricity balloon day was especially popular, because it meant going outside. Artistic students especially loved the rocket day because they got to engage their passions for a significant chunk of class. Overall, even for the least interested students, I think the class was enjoyable, and they learned some physics from the hands-on activities.

Helping the second group of students, those who did not know any physics but were willing to learn, was the most fulfilling part of teaching. Nothing felt better than watching a kid understand something they had not understood before and get excited about it. Kids were amazed by $E = mc^2$, and almost every class had kids who asked, “if there’s so much energy in everything, why can’t we just get energy out of this table or something?”

Of course, time dilation and the double slit experiment also blew kids’ minds. I saved about ten minutes in class just for questions about the double slit experiment. Every class without fail was filled with question after question about how it could be possible. I loved teaching them that sometimes we do not have the answer, and that is one reason why physics is so cool, because there is a lot of room for new discoveries!

In the end, I think I was able to get some from this second group to realize they liked physics. One email from a parent was particularly heartening:

> "Thank you so much. I'm A—'s mother and she's never liked science much, but she's been telling me how interesting it is this summer and how much she's enjoying this course. Thanks for making it interesting and fun for her to learn. It's so great seeing her so enthusiastic about science!"

Another parent emailed me:

> "N— told me he enjoys the science course most in his P— summer program."

In summary, I was happy with the outcome of my class. I think the material was interesting to many students, and the class organization helped those who might not have been interested stay mostly engaged. I helped at least a few students develop their love for physics and STEM.

Challenges Facing STEM Education

Before reviewing academic research on teaching elementary aged children physics, it is helpful to address some problems with physics education.

Currently the United States is facing a shortage of STEM workers. Reportedly, 53% of jobs require some STEM training, while only 43% of workers are qualified. (1) According to Former Representative Rick Lazio "The situation is so dire that American companies are literally turning away business because they can't recruit enough technically skilled workers. . ." (2)

Clearly, the US economy needs more students to take an interest in STEM and go on to study STEM related fields in college. According to research done in England, interest in science and perceived ability to successfully understand science are among several key predictive factors in whether the student will go on to study STEM related subjects. (3) Unfortunately, according to other research done in England, secondary students do not always show a lot of interest in physics. For example, only 6% of students found physics very interesting and only 20% found it interesting at all. 30% did not enjoy the subject, and 48% found physics very difficult. The same study claims that, "there is evidence that the perception of a subject as being difficult tends to result in the development of a general negative attitude to that subject." This is even more pronounced in girls, with 51% finding physics difficult and 32% not enjoying it. (4)

In order to increase the amount of US students studying STEM, something has to be done to increase interest in physics, as physics and mathematics are critical components of most STEM majors. Indeed many solutions have been proposed and tried. Considering I found success in inspiring interest in physics by emphasizing modern physics, I am going to focus on research relating to modern physics, and how it improves children's understanding and enjoyment of physics.

Modern Physics for Elementary Students

One proposed method for increasing students' interest and understanding of physics is spearheaded by the Einstein-First Project, which has been implemented in some Australian schools. According to their website, "The Einstein-First initiative inspires all Year 3 to Year 10 students to: learn about and embrace modern science and technology. . . embrace science, technology and mathematics subjects to study in year 11 and 12 and. . . recognise their own potential future in diverse careers in innovation, technology, science. . ." It aims to accomplish these goals ". . .by developing innovative methods for teaching school age children the concepts of Einsteinian physics." (5)

The Einstein-First Project and its contributors have put out several published papers on their findings and successes. I will briefly survey some of these papers and other papers inspired by the project to show how modern physics may resolve some of the aforementioned issues in modern science education.

One of the first arguments against teaching modern physics is that it may be too difficult for elementary students to understand. However the research does not support this assumption. One 2018 study sponsored by the Einstein-First Project purports to show, "that there is no intrinsic difficulty regarding intelligibility of core Einsteinian concepts at the middle school level of the participants." (Kaur T, Blair D, Stannard W, et al p. 1). The authors of this paper conducted a study in which they gave 14 -15 year old students a questionnaire before and after a 20 lesson course on Einstienian physics, as well as a delayed retention questionnaire one year after the class was completed. The questionnaires included theoretical questions, as well as questions regarding the students' interest in physics. The researchers found that, independent of prior knowledge, theoretical understanding of Einsteinian physics was high after the course. They also found the female attitudes towards physics improved more so than their male counterparts. (6)

Another study by the Einstein-First program showed that for 10 - 11 year olds, "The results indicated a statistically significant improvement in children's conceptual understanding on the pre/post- questionnaire" (Pitts M, Venville G, Blair D, Zadnik M p. 1). These students were given a pre-questionnaire, attended 6 class sessions on space time, then took a post-questionnaire. Analysis of their questionnaire responses shows an increase in understanding of Einsteinian concepts, especially among those who performed poorly on the initial questionnaire (7). Critically, eleven of these students were contacted a little less than 10 years later, and "[all] participant responses included at least one memory about the intervention" (Adams K, Dattatri R, Kaur T, Blair D p. 3). The researchers concluded, "that Einsteinian physics can be taught at the upper primary level and be remembered many years later" (p. 8). Critically, two of the eleven went on to study STEM related majors in college. (8)

Based on these studies, it becomes clear that modern physics is not too difficult for elementary and secondary aged students. Furthermore, there are indications that an Einsteinian rather than a Newtonian approach actually results in increased understanding. In particular, gravity seems to make more sense to children from the perspective of general relativity and space curvature, than from the Newtonian perspective of force interaction. Inspired by the Einstein-First project, researchers in Italy taught general relativity to 10 and 11 year old students. Similar to what I did, they taught students from a 2D approximation of spacetime by placing balls on a stretchy surface. When asked about the nature of gravity before the course on general relativity, 63% explained gravity from a Newtonian perspective as an interaction, 32% did not answer or were wrong, 5% explained some effect of gravity. After the course, 91% explained gravity as a spacetime deformation and only 9% did not answer or were wrong. Besides the fact that the vast majority of students had a solid understanding of Einsteinian gravity after the demonstration, the students who understood Newton's interactive model before abandoned this conceptual framework and moved to general relativity to explain gravity! This indicates that Einstein's model for gravity is more intuitive for children. (9) This accords with my own experience. As a child, I remember watching a planetarium movie about spacetime warping around massive objects, and this effect being responsible for gravity. Ever since then, I have thought about gravity in terms of spacetime, rather than as a force interaction like magnets.

There is also evidence that teaching Einsteinian physics increases girls' interest in physics. According to Kersting et. al., ". . . the issue of young girls' engagement with science and the proportion of girls pursuing careers in science has become a matter of considerable concern among educators and policymakers worldwide" (p. 2). Over a two week period, female students aged 14 - 15 were taught 45 minute daily lectures on Einsteinian Physics. Then the students were given an open ended questionnaire to gauge their interest in physics. Based on their findings, the authors concluded on page 17, "that [Einsteinian Physics], indeed, offers excellent opportunities to inspire middle-school girls to see future possibilities in physics and science." (10)

In 2000, Shabajee and Postlethwaite argued that not teaching children modern physics can actually be detrimental for four reasons. The first is that failing to teach modern physics to children makes it more difficult for them to understand it later on. When they are taught at a young age only about Newtonian physics, modern physics "encountered in a later stage of education. . . is viewed as obscure and impenetrable" (p. 3). Their second reason echoes a previous thought of mine, that modern physics is most often seen in books and television, yet little taught to young students. They argue that modern physics is more likely to excite pupils. The third reason is that failing to teach modern physics lowers the perceived relevance of physics to students, as most modern technology has moved well beyond simple Newtonian calculations. Finally, they argue that teaching only Newtonian concepts limits the creativity of students and teachers in exploring new ways to learn. (11)

In summary, research has shown that children can be taught modern physics and understand it. In fact, some research even shows that modern physics gives children a more intuitive understanding of natural phenomena than the traditional Newtonian approach. Finally, if Shabajee and Postlethwait are to be believed, not teaching modern physics is actually detrimental to science education, as it makes the field less interesting, more difficult, and less relevant.

Ideas for Further Research

If I were able to do this over, I would be most interested in developing more metrics to determine the success of my teaching. Tests are the obvious answer, but that would make me the only teacher in the summer program to offer tests–in other words, very unpopular. Instead, I would probably adopt something more like the survey given by the Einstein-First Program. I would be interested to see not only what the kids know before I teach the class, but what they think about physics in general. After the class, I would give them the same survey to see how their knowledge and opinions changed. Hopefully, that would give me some good data points to see just how successful I was.

Furthermore, I would love to get some data a few years down the road. Do the students remember the class? Do they remember enjoying it? Do they remember anything they learned specifically? How has it influenced their life/ schooling/ career? This is potentially possible, since the school I taught at retains information on all students. I do not know if they would let me contact the students in a few years, but I think it is worth looking into.

As for the actual curriculum, there is not much I would change. Luckily, because I was able to teach each class several times, it was clear to me what worked and what did not pretty quickly so I could change it for the next group of students. As such, I adapted and changed the curriculum while I was teaching. With surveys in place though, I might realize there were concepts not as well understood as I thought.

Were I to teach modern physics outside of the particular program from last summer, I would want several more weeks to dive deeper into each topic. I think the double slit experiment and quantum mechanics especially could be explored with a lot more clarity given several class periods.

I guess I will see if I ever get the opportunity to try this again!

CONCLUSION

Over the course of this paper, I have shown that modern physics can be successfully taught to children. I organized and taught a curriculum of some of the major discoveries of the last 100 years, designed to elicit wonder in young minds. Over the course of 10 class periods, I introduced several different groups of kids to some of the most amazing things we know. I believe I was successful in teaching the difficult concepts in a way that could be understood and appreciated by young students. Other research in this field supports my own experience, with some educators even suggesting that starting children on modern physics may be preferable in some cases to a Newtonian explanation.

Personally, I thoroughly enjoyed planning my class, thinking up demonstrations, and teaching material that I find fascinating and wonder-inducing. I like to think that if I were a kid, I would have loved my class!

ACKNOWLEDGEMENTS

I could not have accomplished this project without the help of several people. I would like to thank Dr. Adam Bennion, my Capstone Advisor who devoted time to helping me find sources, editing my paper, making suggestions, and serving as a mentor throughout the process. I would like to thank the administration of the school I worked at for letting me design my own course, as well as the students for showing up each day ready to learn! Thanks to the BYU physics education students and Professor Duane Merrell who let me present during their class. Thanks to my mom, a high school teacher, for helping me learn how to teach. Thanks to the BYU physics department for the learning opportunities I have had. And thanks to Carlo Rovelli for rekindling my love of physics!

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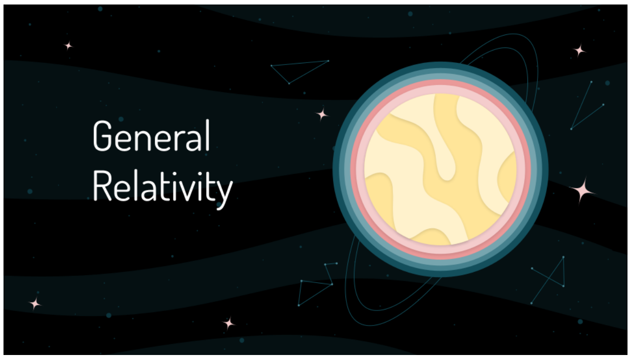
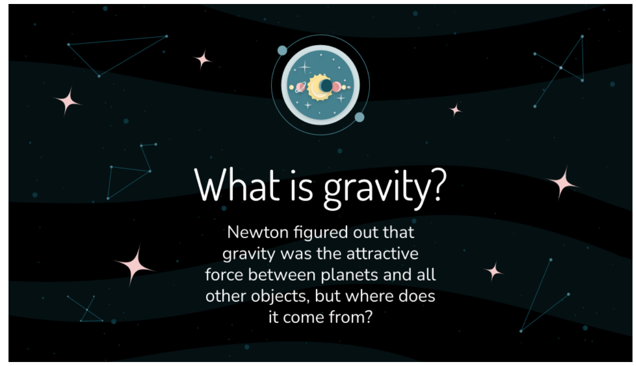
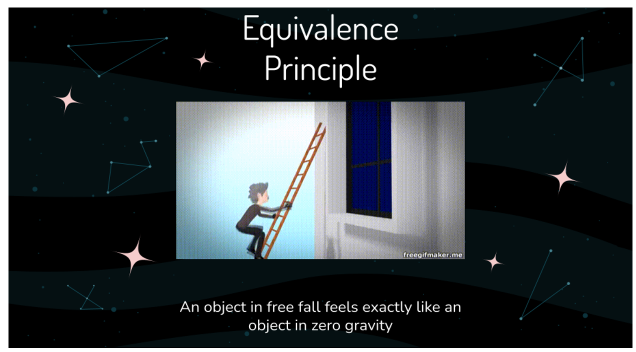
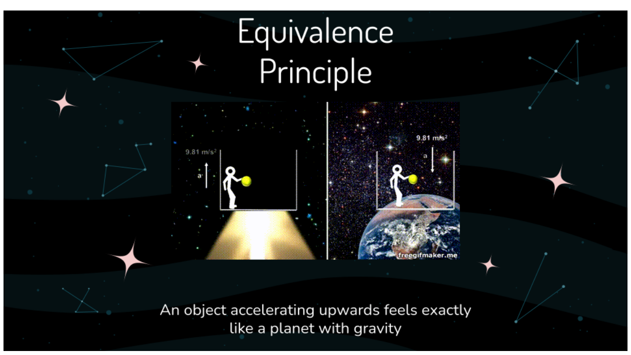
APPENDIX A

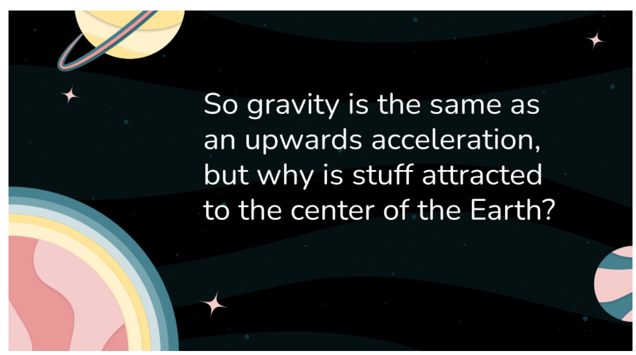
Lecture Slides Example: General Relativity

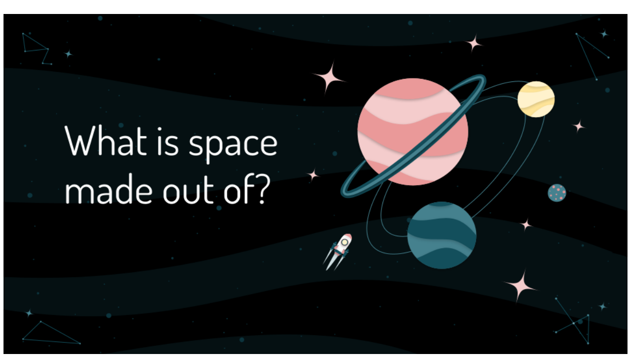


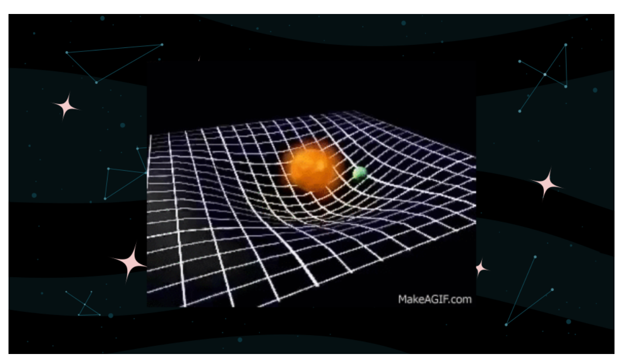


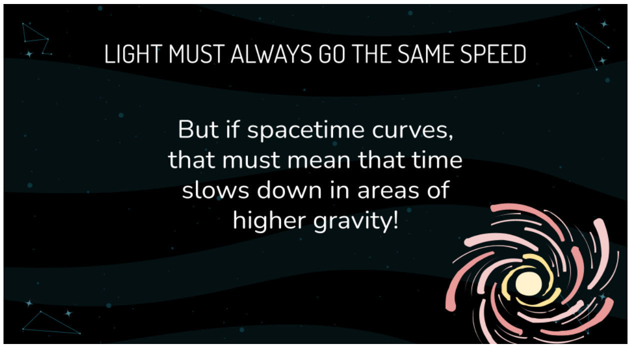


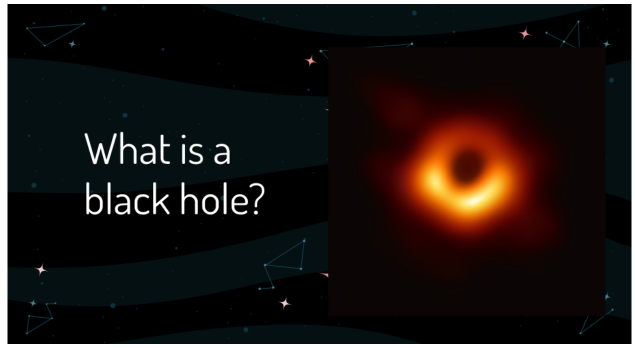


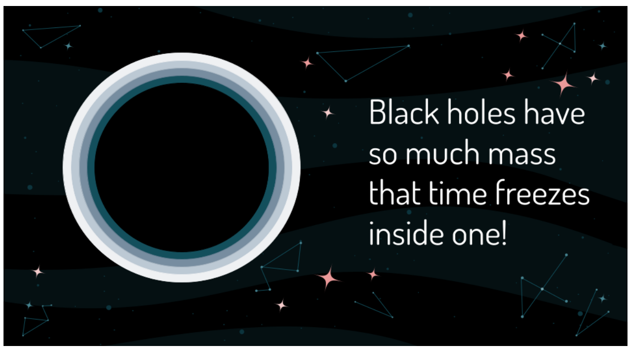


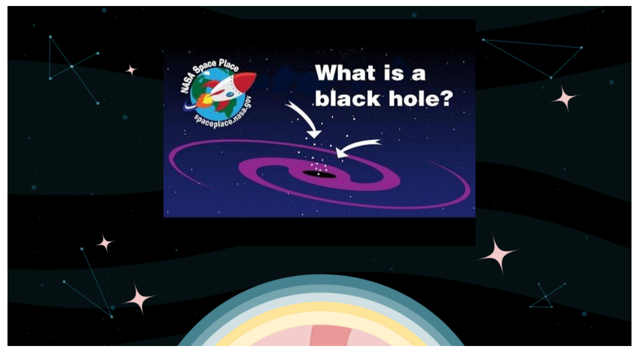




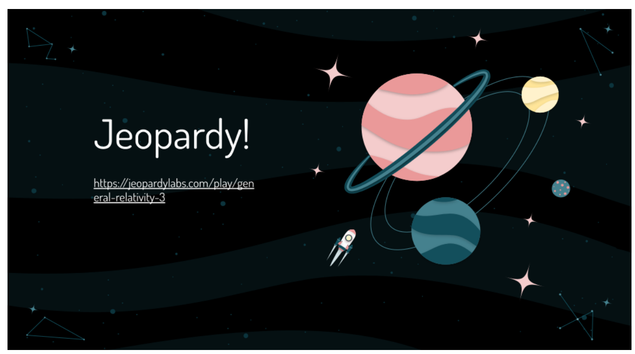

LIGHT MUST ALWAYS GO THE SAME SPEED
But if spacetime curves, that must mean that time slows down in areas of higher gravity!


What is a black hole?


Black holes have so much mass that time freezes inside one!

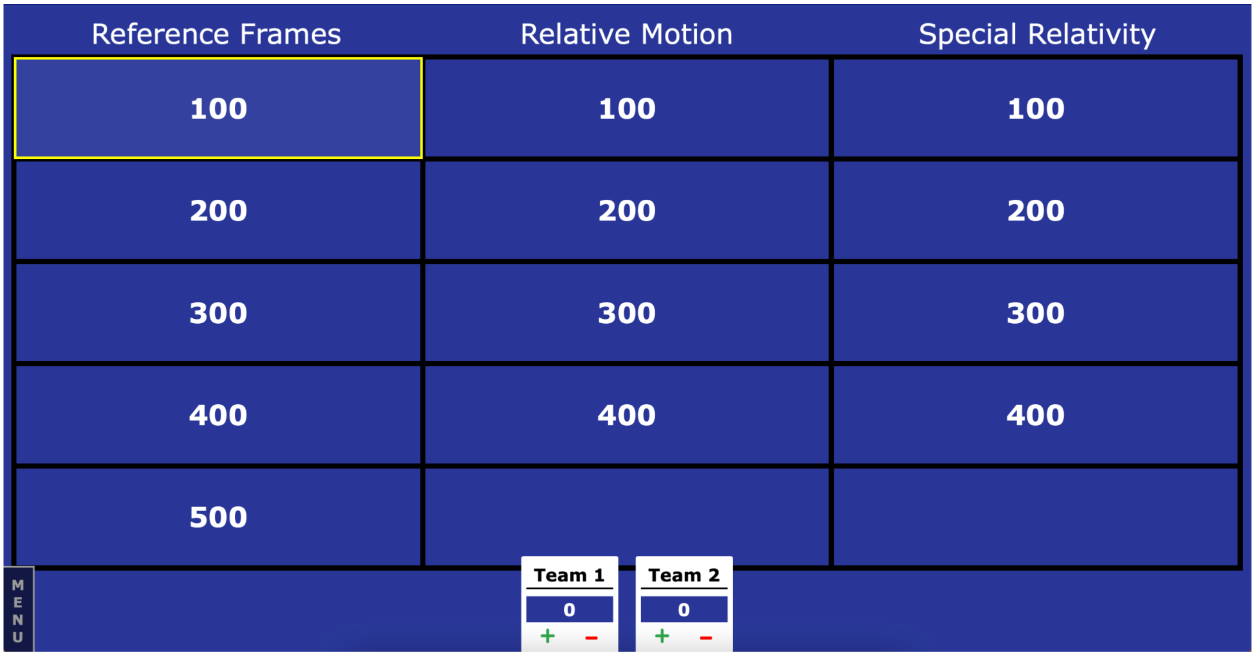

What is a black hole?

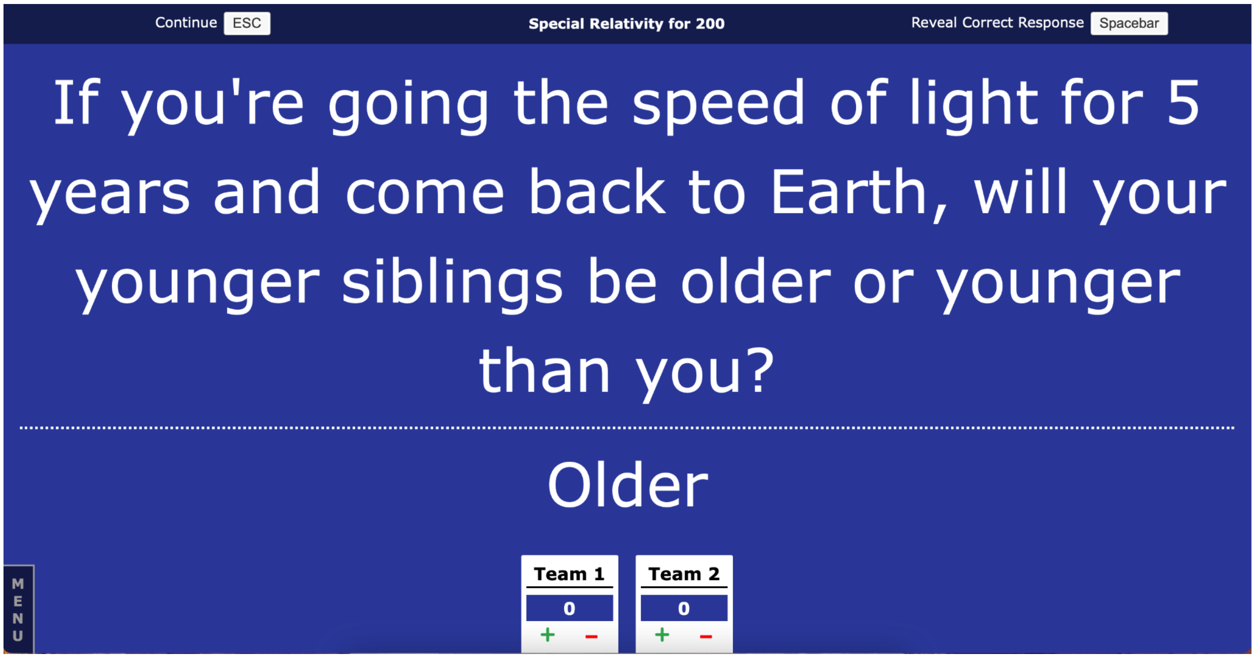

Interstellar

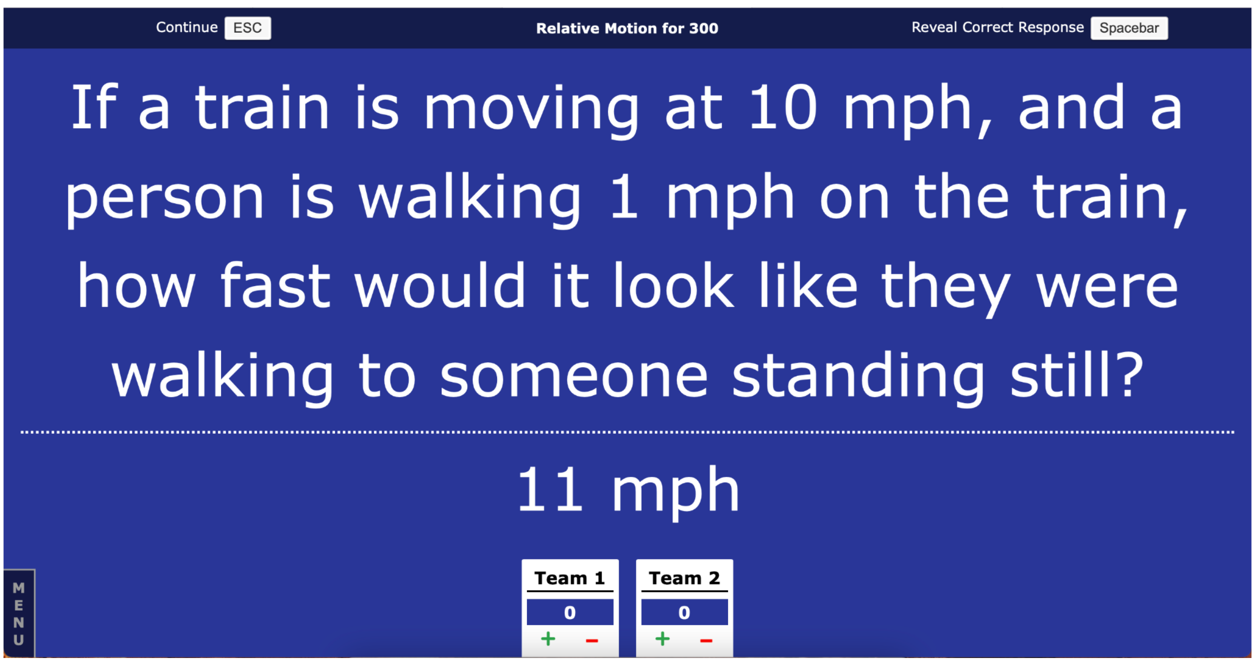

Jeopardy!
https://jeopardylabs.com/play/gen
eral-relativity-3

APPENDIX B

Jeopardy Game Example: Special Relativity




Continue ESC
Special Relativity for 200
Reveal Correct Response Spacebar
If you're going the speed of light for 5 years and come back to Earth, will your younger siblings be older or younger than you?
Older
MENU
Team 1
0
Team 2
0


Continue ESC
Relative Motion for 300
Reveal Correct Response Spacebar
If a train is moving at 10 mph, and a person is walking 1 mph on the train, how fast would it look like they were walking to someone standing still?
11 mph
MENU
Team 1
0
Team 2
0